

# International Geology Review

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## IGR transliteration of Russian

The AGI Translation Office has adopted the Cyrillic transliteration recommended by the U. S. Department of the Interior, Board on Geographic Names, Washington, D. C.

## NOTES:

- (1) "ye" initially, after vowels, and after *и, ё* ;  
"e" elsewhere; when written as "ë"  
in Russian, transliterate as "yë" or  
"ë".

Well-known place and personal names that have wide acceptance will be used. Some translations may include elements of previous German transliteration from the Russian; this occurs in IGR most commonly in maps and lists of references. The reader's attention is called to the following variations between German and English systems which may cause confusion when trying to check back to original Russian sources.

| Alphabet |   | transliteration      |
|----------|---|----------------------|
| А        | а | a                    |
| Б        | б | b                    |
| В        | в | v                    |
| Г        | г | g                    |
| Д        | д | d                    |
| Е        | е | e, ye <sup>(1)</sup> |
| Ё        | ё | ë, yë                |
| Ж        | ж | zh                   |
| З        | з | z                    |
| И        | и | i                    |
| Й        | й | y                    |
| К        | к | k                    |
| Л        | л | l                    |
| М        | м | m                    |
| Н        | н | n                    |
| О        | о | o                    |
| П        | п | p                    |
| Р        | р | r                    |
| С        | с | s                    |
| Т        | т | t                    |
| У        | у | u                    |
| Ф        | ф | f                    |
| Х        | х | kh                   |
| Ц        | ц | ts                   |
| Ч        | ч | ch                   |
| Ш        | ш | sh                   |
| Щ        | щ | shch                 |
| Ъ        | ъ | "                    |
| Ы        | ы | y                    |
| Ь        | ь | ,                    |
| Э        | э | e                    |
| Ю        | ю | yu                   |
| Я        | я | ya                   |

| German  | English |
|---------|---------|
| w       | v       |
| s       | z       |
| ch      | kh      |
| tz      | ts      |
| tsch    | ch      |
| sch     | sh      |
| schtsch | shch    |
| ja      | ya      |
| ju      | yu      |

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# ON THE ORIGIN OF SEDIMENTARY DOLOMITES<sup>1</sup>

by

G. I. Teodorovich<sup>2</sup>

translated by Ivan Mittin

## ABSTRACT

The author sets forth his ideas about the formation of dolomite rocks, according to prolonged mineralogical and petrographic investigations and in accordance with experimental physical and chemical data received by O. K. Yanatyeva. It is shown that formation of dolomites may take place in various ways, and that means of dolomitization by replacement are diverse, it being known that phenomena of lime sediment replacement are predominant. Basic characteristics of primary chemical and of replacement dolomites belonging to the period of sediment diagenesis are established. Six principal cases of the formation of replacement dolomites after  $\text{CaCO}_3$  limes are distinguished. During the Precambrian and the Paleozoic  $\text{CO}_2$  in the atmosphere was much higher than at present; according to the author this contributed to the broadness of the "field of dolomite formations" at that time. In most cases the increase in salinity to a certain limit favors the formation of dolomites equalizing the solubilities of dolomite and of calcite. This work contains also some criticism of N. M. Strakhov's ideas stated in an article entitled "Facts and Hypotheses in the Problem of Dolomite Rock Formations" (Izvestiya, U. S. S. R. Academy of Sciences, Geology series, no. 6, 1958) as giving a fallacious interpretation of the principal questions raised. The relation of the overwhelming majority of fossil dolomites to seas and lagoons is shown in the article. The vast development in nature — particularly in Paleozoic sediments — of primary sulfate-dolomite and of dolomite-sulfate rocks, as well as the dolomite content of most anhydrite and gypsum confirms the ideas of the author about the frequent formation of dolomite in saline lagoons involving  $\text{MgCO}_3$ , not in cases however of high  $\text{MgCO}_3$  concentration in the solution. --Author's English summary.

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One of the most complex problems in the science of sedimentary rocks is the formation of dolomite rocks. No unanimous opinion exists on the extent of distribution of basic genetic types of dolomite under natural conditions.

All existing concepts of the origin of sedimentary dolomite can be brought down to three basic manners of the formation of dolomite:

1) Dolomitization of existing limestones during epigenesis; 2) Dolomitization of calcareous or magnesian-calcareous muds, i. e., during diagenesis of sediments; 3) Chemical precipitation from solutions and accumulation of dolomite as sediment on the bottom of continental basins. Besides, some writers associate the formation of dolomite with the leaching of  $\text{CaCO}_3$  from existing dolomitic limestones and calcitic dolomites, leaving the question of the genesis of the dolomite itself open.

In 1942 this author, on the basis of the mineralogic-petrographic investigation of calcareous dolomites of the upper Paleozoic of Bashkiriya, arrived at a conclusion that the formation of dolomite can take place in various manners, and that dolomitization processes by replacement vary, the processes of the re-

placement of calcareous sediments being of primary importance. At that time we also pointed out that dolomitization can be many-phased, and that dolomite formation can take place differently at different phases, and that the main phase may coincide with different stages of diagenesis and, sometimes, epigenesis.

In 1950 (p. 23) we noted the main types of dolomite formation distinguished by the character of the process and its duration, namely: 1) The primary deposition of dolomite from basin waters; 2) Dolomitization by substitution, early diagenesis, late diagenesis and epigenesis. The formation of dolomite is known (to have taken place) in reservoirs differing in the degree of mineralization and the character of the salt mass: in oceans; in lagoons with a low salinity; in salt-bearing lagoons saturated with respect to  $\text{CaSO}_4$ ; in interior lakes of different salinity in arid climates. In our opinion (Teodorovich, 1950, 1955), main factors in the formation of dolomite are: relative composition of dissolved salts (cation and anion) or type of water; partial pressure of  $\text{CO}_2$ ; temperature of water; magnitude of pH.

The basic features of the primary chemogenous dolomites are their pelitomorph texture, maintained sheet-like structure, pure or almost pure dolomitic composition and density of the rock. Dolomite formed by replacement develops preferably on fine-grained  $\text{CaCO}_3$  while sections of coarse-grained  $\text{CaCO}_3$  are not

<sup>1</sup>Translated from: Oproiskhozhdenii osadochnogo dolomita, Sovetskaya Geologiya, no. 5, 1960, pp. 74-87. Reviewed for technical content and edited by Curt Teichert.

<sup>2</sup>Institute of Geology and Mineral Development, Akademii Nauk, SSSR.



favorable for dolomitization (Teodorovich 1931, 1935, 1942, 1945).

Let us consider various instances of the origin of dolomites by replacement of calcareous or magnesian-calcareous muds.

1. In the acidification zone of calcareous mud, with  $\text{CaCO}_3$  partially dissolved, the readily soluble magnesium carbonate of skeleton remains of marine organisms of the magnesian-calcareous group (Vinogradov, 1937; Clark and Wheeler, 1922; Vesterberg, 1900, and others) changes entirely (under the influence of  $\text{CO}_2$  liberated during the decomposition of organic matter) to a mud mixture and yields considerable additional portions of  $\text{MgCO}_3$  which lead to the saturation of the solution with dolomite. The relative deficiency in  $\text{MgCO}_3$  of fossil skeleton remains of organisms such as echinoderms in contrast to their rich modern forms can be easily explained. The readily soluble  $\text{MgCO}_3$  of finely porous skeleton accumulations of modern echinoderms easily goes into solution. Analogously, in the remains of the fossil skeletons of organisms of the calcareous-magnesian group (especially echinoderms)  $\text{MgCO}_3$  also goes quickly into solution already during initial stages of the diagenesis of sediments.

2. A slow sustained movement of warm (about  $25^\circ$ ) sea water over calcareous mud results in its noticeable enrichment in magnesium carbonate or directly with dolomite (Riviere, 1939a and 1939b). The intensity of dolomitization here depends on the fineness of the grain size and on the porosity of the calcareous mud, the duration of the sustained water flow and partial pressure of carbon dioxide ( $\text{pCO}_2$ ) in the atmosphere; the increase of pressure aids dolomitization, indicating a more intensive replacement of calcareous mud by dolomite in the geologic past, particularly in the Paleozoic.

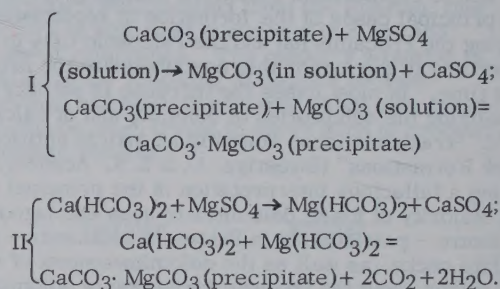
3. Ammonium in compounds connected with the decomposition of organic matter in the form of  $(\text{NH}_4)_2\text{CO}_3$  tends to react with  $\text{MgCl}_2$  of the sea water and with  $\text{MgSO}_4$  furnishing new batches of  $\text{MgCO}_3$ : a) - at average temperatures  $(\text{NH}_4)_2\text{CO}_3 + \text{MgCl}_2 + 3\text{H}_2\text{O} = 2\text{NH}_4\text{Cl} + \text{MgCO}_3 \cdot 3\text{H}_2\text{O}$ ; b) - at raised temperatures  $4(\text{NH}_4)_2\text{CO}_3 + 4\text{MgCl}_2 + \text{H}_2\text{O} = 8\text{NH}_4\text{Cl} + \text{Mg}_4(\text{CO}_3)_3(\text{OH})_2 + \text{CO}_2$ .

Accumulation in calcareous mud of  $\text{MgCO}_3$  or  $\text{Mg}_4(\text{CO}_3)_3(\text{OH})_2$  leads to saturation of solution with dolomite. In the geologic past, to be exact in the Paleozoic, when high  $\text{pCO}_2$  occurred normally, and when life had already developed widely, conditions for the formation of dolomite in the manner described were especially favorable.

4. According to a number of researchers

(Daly, 1910; Teodorovich, 1931, and others),  $\text{CaCO}_3$  is precipitated from sea water first, followed by basic magnesium carbonates or  $\text{Mg}(\text{OH})_2$  which change in sediments to dolomite, accompanied by the replacement of  $\text{CaCO}_3$ . Such a replacement must be expressed especially well in case of the chemical precipitation of  $\text{CaCO}_3$  with admixture of magnesium carbonates.

5. If the salinity of sea water increases, approaching or attaining the saturation of the solution with  $\text{CaSO}_4$ , the Haidinger reaction - I (in water the N. S. Kurnakov reaction - II) comes into effect in two stages (Teodorovich, 1950, p. 73):



If concentrations of  $\text{MgSO}_4$  in the solution are high and correspond to the mineralization that approaches or is higher than that of the saturated  $\text{NaCl}$  solution, (then) dolomite is not stable, and only the first stage of the reaction with  $\text{MgSO}_4$  takes place, accompanied by the formation of magnesite or hydromagnesite:  $\text{CaCO}_3 + \text{MgSO}_4 = \text{CaSO}_4 (\text{precipitate}) + \text{MgCO}_3 (\text{precipitate})$ .

Replacement of calcareous mud, often already containing an admixture of  $\text{MgCO}_3$  (either in the composition of skeletons of organisms or as basic salts and hydrated Mg salts), results in formation of lens-like or sheet-like, sometimes micro-mottled calcareous-dolomitic rocks. These rocks differ from primary chemogenous dolomites by being less consistent in stratification, in a relatively coarser grain-texture, and, as a rule, in a lesser content of dolomite in connection with the usually incomplete replacement of  $\text{CaCO}_3$ . Frequently, as a result of epigenetic leaching, these existing calcareous dolomitic rocks become friable, porous and cavernous, more dolomitic and, not infrequently, they are characterized by an increased amount of insoluble residue (Teodorovich 1931, 1946b, 1950).

6. In his articles in 1956 (a and b) N. M. Strakhov assumes that in the Paleozoic dolomite precipitated in marine basins primarily as an admixture in chemogenous  $\text{CaCO}_3$ , and that during diagenesis it experienced displacements and became enriched in particular places (patches, or lenses) of the mud.



In considering alternating carbonate parageneses of the ancient lagoon and marine deposits, it is also necessary to take into account that, in addition to the salt composition of waters and their mineralization, the  $p\text{CO}_2$  in the atmosphere of the Paleozoic and Precambrian was much higher than of recent time; it caused an increase of the width of the "field of dolomite formation" in Paleozoic time as compared with recent time (Teodorovich 1950, 1955). O. K. Yanatyeva (1949, 1950) demonstrated that 1) at the same temperature, for instance  $25^\circ$ , the area of formation and stabilization of dolomite in the system  $\text{CaCO}_3\text{-MgCO}_3\text{-H}_2\text{O}$  is much larger for  $p\text{CO}_2=1$  atm, than for  $p\text{CO}_2=0.0012$  atm or even more so for  $p\text{CO}_2=0.0003$  atm; 2) for relatively small concentrations of magnesium sulfate and in the presence of NaCl "the lowest solubility of dolomite is for  $p\text{CO}_2\sim 1$  atm., and of calcite — for  $p\text{CO}_2\sim 0.0012$  atm, and the position of dolomite here is intermediate in the series of the three carbonates" (Yanatyeva, 1954, p. 1120).

In considering higher values of  $p\text{CO}_2$  and actual distribution of various types of dolomites, one can arrive at the conclusion that: 1) In the Precambrian and Lower Paleozoic primary chemogenous dolomites dominated; 2) Dolomites as replacement during diagenesis of the sediment were forming in seas of the Upper Paleozoic while primary dolomites were forming in salt-water lagoons and in large sea-bays of low salinity content; 3) In the Mesozoic and Cenozoic, because of a considerable decrease in the  $p\text{CO}_2$  value, the role of dolomites among the sedimentary carbonate rocks declined sharply and the replacement type of dolomite became dominant (Vinogradov, 1952; Strakhov, 1951; Teodorovich, 1950; Yanatyeva, 1949, 1950).

The formation of primary dolomite devoid of fauna or containing hypersaline marine fauna only in isolated lenses, and the formation of primary mottled (and other types of) sulfate-dolomitic rocks took place in those very shallow somewhat saline epicontinental seas of the

Upper Paleozoic, which represented large saline embayments, and in the lagoons saturated with  $\text{CaSO}_4$ . When in these lagoons the  $\text{MgSO}_4$  content in the solution increased because of evaporation, then the formation of dolomite discontinued because under these conditions only the first stage of the Haidinger and N. S. Kurnakov reactions accompanied by the formation of  $\text{MgCO}_3\cdot 3\text{H}_2\text{O}$ ,  $\text{MgCO}_3$  or  $\text{Mg}_4(\text{CO}_3)_3(\text{OH})_2$  and  $\text{CaSO}_4$  can take place.

As has been established for carbonate-sulfate rocks of the Paleozoic (Teodorovich, 1942, 1946b), this disappearance of dolomite in waters of non-metamorphized lagoons<sup>3</sup> proceeded because of an increase in the content of  $\text{MgSO}_4$ , with their mineralization approaching a saturated solution of NaCl.

In the present sea water the percent ratio of  $\text{MgSO}_4$  to the water weight is 0.17. During the isothermal ( $40^\circ\text{C}$ ) evaporation of normal sea water (Mediterranean), the beginning of precipitation of NaCl corresponds to a  $\text{MgSO}_4$  content = 1.87 percent of the water weight (Usiglio, 1849a and 1849b). Though the salinity of Paleozoic sea water is not exactly known, it can be roughly estimated that with values of  $p\text{CO}_2$  in that period being definitely high, the formation of dolomite was superseded by the formation of magnesite in the Upper Paleozoic lagoons (containing non-metamorphized or slightly metamorphized water) with an  $\text{MgCO}_3$  content of 2 percent of the water weight. At present under conditions of a low partial pressure of  $\text{CO}_2$  equalling 0.0003 atm. dolomite is usually dissolved incongruently (?) (with precipitation of calcite and accumulation of magnesium in the solution); consequently, "The field of formation" of dolomite is sharply reduced. Therefore, at present, the formation of dolomite requires either an increased  $p\text{CO}_2$  in muddy water, or its enrichment with additional quantities of  $\text{MgCO}_3$ , a factor that on the whole determines the possibility of dolomitization by replacement during diagenesis of the sediment; or a sulfate-hydrocarbonate composition of water (particularly "soda" composition) that effects the original precipitation of magne-

<sup>3</sup> Since the concept of "metamorphization" of water is unfamiliar to geologists in this country the following translation from "Geologicheskoy Slovar", A. N. Kristofovich, v. 2, Moscow, 1955, p. 31, may be helpful: "The metamorphization of waters is the interaction between water (brine) and the surrounding medium under existing conditions, that leads to a directional change of the chemical composition of water (brine). Inasmuch as all waters can be subdivided into the three basic chemical types, carbonate, sulfate and chloride, the process of metamorphization of any of these types leads to a gradual change in the salt composition of water and to (its) change into a different type. If in the course of metamorphization the composition of water changes from the carbonate to sulfate and then to chloride type, i.e., it first results in the loss of  $\text{CO}_3^{2+}(\text{HCO}_3^+)$ , then in the loss of  $\text{SO}_4^{2+}$ , such a course of metamorphization is called direct or normal (metamorphization of the first kind). Such a process takes place in arid climate in a downward direction (underground waters). The change in the water composition in reversed direction, i.e., the accumulation of  $\text{SO}_4^{2+}$  and then of  $\text{CO}_3^{2+}$  and  $\text{HCO}_3^+$  in solution (which is also a widespread process) is called reversed or inverted (metamorphization of the second kind). This process is associated with humid climate and with an increase of water supply. The term has been proposed by Kurnakov to indicate the process of the change in the composition of sea water (the loss of  $\text{SO}_4^{2+}$ ) caused by land water in salt lakes of the Crimea." — C. T.



sium from the solution in the form of carbonates, including dolomite; or a high general content of magnesium salts in water with low concentrations of  $MgSO_4$ .

Thus, the basic factor in the change of carbonate parageneses in ancient saline lagoons is a progressive increase in salinity of their waters: a dolomitic carbonate component (with admixture of calcite) being replaced by a calcite-magnesite one, and the solution attaining saturation with NaCl. Individual deviations from this scheme (Teodorovich, 1942, 1946b), such as the presence of dolomite in certain halites, can be attributed to the metamorphization of lagoon waters, to a sharply reduced, even totally absent  $MgSO_4$  in the solution (Teodorovich, 1955).

Thus, the salinity increase up to a certain limit contributes in most cases to the formation of dolomite narrowing the gap between the solubilities of dolomite and calcite. Though we do not reject possibility of the formation of dolomite in cases of slight freshening of the water in relatively small marine embayments, yet this can take place mainly not by simple dilution, but because of the change of the saline composition in sea water, apparently, with a considerable content of  $MgCO_3$ , hydrocarbonate and magnesium chloride in waters entering from the land, under condition that the land and basin are situated in the arid climate belt. In these cases the formation of dolomite does not take place at the expense of the decreasing salinity but because of the change in the composition of dissolved salts; i.e., as a result of the transition of the basin water from one type to another.

We have shown (Teodorovich, 1946b, 1950) that there is connection between the predominant mass of ancient dolomites and seas and lagoons, and we outlined four groups of dolomite formations. It has also been established (Teodorovich 1950, 1955) that, on the whole, the role of primary dolomites decreases rhythmically from more ancient to more recent phases of the earth's history. The importance of the climatic factor was properly stressed by N. M. Strakhov (Strakhov, 1945).

Study of mineralization changes for various types of water showed that the water types (the relative composition of dissolved salts) and their mineralization play a big role in the sequence of precipitation of salts of marine lagoons, saline and briny lakes and their bays that become salty. Analysis of changes in the composition of dissolved salts during evaporation of each water type permits not only explanation of certain facts of the change of carbonate parageneses of continental lakes, marine lagoons, and lakes and seas, but also it yields prognoses with regard to the change of parageneses. It is the occurring change in the relative composition of the salts dissolved rather than the softening of the basin waters or in its bays, that may

sometimes lead to the formation of dolomite.

On the basis of a detailed study in 1950 of dolomites and dolomite-containing rocks of the Paleozoic of the Ural-Volga region we (Teodorovich, 1955) separated and characterized the following facies groups and types of these rocks:

1. Normal marine calcareous-dolomitic deposits and dolomites such as limestone-dolomite deposition in shallow sea water, in the presence of bottom currents, (and) with redistribution of  $MgCO_3$  of organic skeletons as a result of the interaction of  $(NH_4)_2CO_3$  and  $MgCl_2$ , etc.; dolomitic deposits in the middle part of the shelf associated with upwelling bottom currents, frequently in foredeeps.

2. Dolomitic and calcareous-dolomitic deposits of saline seas, lagoon-like bays and periodically dry calcareous muds: in slightly saline epicontinental seas; in epicontinental seas with a noticeably high salinity; in peculiar narrow saline seas; in seaside lagoons that became saline; in specific bays on reefs and periodically dry calcareous muds splashed with sea water.

3. Dolomitic deposits in definitely saline lagoons, such as those approaching saturation with  $CaSO_4$  (dolomites characterized with microgranular and relict fine-lumpy or oolitic textures); saturated or periodically saturated with respect to  $CaSO_4$  (characteristic are primary-mottled, fine platy and other sulfate-dolomitic rocks, gypsum and anhydrite-containing dolomite).

In an article in 1956 (a), N. M. Strakhov, in sharing the accepted opinion on the wide distribution of dolomitic deposits in the geologic past that are associated one way or another with marine reservoirs, distinguishes among them four facies types. One cannot but note that these types of dolomite do not include many of their commonly known facies types generally associated with sea water. Particularly, N. M. Strakhov does not even mention the marine dolomites and calcareous-dolomitic deposits formed by bottom currents in foredeeps described by many writers (Teodorovich 1949, 1950; Khvorova, 1956), as well as the shallow sea-water epicontinental dolomites by currents (by replacement). Neither does he recognize another facies type, the primary sulfate-dolomitic rocks, actually existing and widely distributed in the Paleozoic.

The wide development in nature, especially in the Paleozoic deposits, of primary (mottled and other types) sulfate-dolomitic and dolomite-sulfate rocks, as well as the dolomite-carrying capacity of the majority of anhydrites and gypsums, is attributed to the formation of dolomite in saline lagoons with  $MgSO_4$  participating but not in high concentrations in the solution. This is substantiated also by experimental investigations by O. K. Yanatyeva (1949, 1950).



Existing natural facts indicate that from the beginning of precipitation of halite, or, more accurately, already in the sulfate sediments deposited immediately before the saturation of the solution with NaCl, magnesite becomes the principal carbonate. On the other hand, dolomite can be the principal carbonate in halites precipitated in lagoons with metamorphized waters lacking or almost lacking  $\text{MgSO}_4$ , and comprising a very small percent of the rock.

In 1958, N. M. Strakhov published an article on the formation of dolomite rocks, in which many of the questions under discussion were elucidated unobjectively. He ignores the intrinsic review of his concepts in the field of formation of dolomite (Sokolov, 1955; Teodorovich, 1955, 1957), and the concepts of a number of writers are not related accurately. Thus, the following assertion by Strakhov (1958, p. 17) does not agree with the facts: "Lately, an opinion has been advanced in the literature on numerous occasions that dolomite is less soluble than calcite". However no one has advanced such a statement in that manner, and the lesser solubility of dolomite was indicated for high  $\text{pCO}_2$  equaling 1 atm., or close to it, as established experimentally by O. K. Yanatyeva (1949, 1950).

A statement by Strakhov that our comparing of solubilities of  $\text{CaCO}_3$  and  $\text{MgCO}_3$  does not explain the formation of dolomite, is obsolete, because lately, in connection with the data on the solubility of dolomite obtained by O. K. Yanatyeva (1949, 1950, 1955a and b), we (Teodorovich, 1957) have been using first-hand information on solubilities of  $\text{CaCO}_3$  and dolomite; they, indeed, are approaching each other with increasing salinity of the sea water from normal to saturated with  $\text{CaSO}_4$ , with rising water temperature (to  $25^\circ\text{C}$ ), and, especially with increasing  $\text{pCO}_2$ ; with high  $\text{pCO}_2$  the solubility of dolomite is less than that of calcite (Yanatyeva, 1949, 1950).

In his article Strakhov (1958) discusses six basic facts which he considers to be important in solving the problem of the genesis of dolomite rocks.

1. The first basic fact "the polyfacies nature of dolomite rocks" agrees with our earlier statements (1942-1950) that the formation of sedimentary dolomite proceeds in various ways in different types of basins or parts of them (Teodorovich, 1942, 1945, 1950).

2. The segregation by N. M. Strakhov of the two principal types of dolomite as "sheet-like" and "mottled metasomatic" types is merely an inadequate renaming of the two types "primary chemogenous" and "diagenetically changed" which were recognized long ago. It is well known that not only primary but diagenetically changed dolomites can be "sheet-

like" dolomites, and the adjective "mottled" can be applied only to some and, moreover, a lesser part of the diagenetic dolomites.

One cannot even agree with Strakhov (1958, p. 4) that dolomites by replacement are always characterized by an "unusual variability in the degree of dolomite content"; this statement is incorrect in most cases.

3. It is generally known that in the predominant number of cases, calcite precipitates first, followed by dolomite and later by sulfates; this was noted by A. D. Arkhangelsky (1923), L. V. Pustovalov (1940) and by many other writers. Strakhov (1958, p. 5) stresses that "the sequence of the formation of minerals is always the same: first calcite, then, when the salinity increases, dolomite". However, for the formation of dolomites by replacement during diagenetic changes of the sediment, which were widely distributed in the Upper Paleozoic and afterwards, the increase of the salinity of water is not necessary at all (Teodorovich, 1946b, 1950, 1955).

4. N. M. Strakhov asserts in an article in 1946 that he and A. I. Tsvetkov "for the first time ... ascertained" (italics are ours - G. T.) that "the formation of dolomite follows that of calcite and attains its maximum during the deposition of gypsum. After that the process of formation diminishes abruptly and at high salinities, close to the precipitation of halite, separate depositions of calcite and magnesite take place instead" (Strakhov, 1958, p. 9). However, in our article in 1942 (p. 176) we proved for saline lagoons of the Paleozoic that "the concentration of salts in a solution during the formation of dolomite here did not attain, as a rule, values corresponding to the saturation of the solution with NaCl and so much more with magnesium sulfate, in other words, it corresponded ... to the saturation of the solution only with  $\text{CaSO}_4$ ".

These facts established by us are in conformity with the results of study of the solubility of dolomite by O. K. Yanatyeva (1949).

5. Rightly, Strakhov regards  $\text{pCO}_2$  as one of the basic facts important for understanding the genesis of dolomite. The great role of  $\text{pCO}_2$  in the formation of dolomite was noted earlier by O. K. Yanatyeva (1949; N. Kolaev et al., 1941), N. M. Strakhov (1949, 1951, 1956b), by us (1950, 1955) and by some other writers. It is of interest, that S. Arrhenius (1924, 1925) has used the idea of the abundance of carbon dioxide in the earth's atmosphere during the ancient periods of its history.

6. Ideas regarding the decrease in intensity of the formation of dolomite from more ancient to more recent geologic epochs, and the periodicity of the character of this process already



have their history. A general decrease of the content of dolomites in the course of geologic time was observed by Daly in 1910 and later by A. P. Vinogradov and A. B. Ronov (1952), G. Chilingar (1953, 1956). The periodicity of epochs of the broad formation of dolomite in the history of the earth was noted by Longchambon (1914a and 1914b), A. D. Arkhangelsky (1923), and later by L. V. Pustovalov (1940), by us (1950), G. Chilingar (1953, 1956) and by other writers.

The second section of the article by N. M. Strakhov (1958) contains mainly his critical reviews of the concepts of the formation of dolomite by S. G. Vishnyakov and G. I. Teodorovich. Almost all of these reviews had already been reflected in his works in 1956 (Strakhov, 1956a and 1956b); it was rather pointless to take the same exceptions again in articles of 1958.

That section begins with enumerating three basic points of view regarding the genesis of dolomite in the Paleozoic deposits: 1) Primary and epigenetic dolomites (M. E. Noinisky); 2) Primary and diagenetic (G. I. Teodorovich); 3) Dolomites all primary, sheet-like dolomites having been originally deficient in  $\text{CaCO}_3$  and mottled calcareous-dolomitic rocks originating as the result of displacements and concentration of dolomite into mottled sections during diagenesis (N. M. Strakhov).

Strakhov asserts that diagenetic calcareous-dolomitic rocks are mottled in character, i. e.; they are distinguished by a strongly irregular distribution of dolomite. Although such calcareous-dolomitic rocks do occur in nature, the majority of dolomitic limestones and calcitic dolomites of the Paleozoic are characterized by small fluctuations in the average content of dolomite. This follows first of all from the fact that no "spots" indicating dense accumulations of dolomitic grains are observed in them, either megascopically or microscopically.

Views of diagenesis are presented incorrectly by N. M. Strakhov (1958, p. 13): "...according to the diagenetic conception, calcareous sediments are deposited on the sea bottom first, and the accumulation of Mg in sediment takes place during diagenesis by way of absorption by sediment of Mg from the bottom water". However, according to the diagenetic conception, dolomitization of marine mud is accomplished at least in four ways, first of all at the expense of easily soluble magnesium carbonate from shell remains of marine organisms of the magnesium-calcium group. Under conditions of a slight increase of the salinity of sea water, approximating the saturation of the solution with  $\text{CaSO}_4$ , dolomitization proceeds by means of the Haidinger reaction in which  $\text{CaCO}_3$  of the sediment interacts with  $\text{MgSO}_4$  and yields dolomite, and also by means of precipitation of an admixture of the chemogenous dolomite (to

$\text{CaCO}_3$ ) and its diffusion, but not by replacement in the mud as Strakhov suggests.

In two instances of the above-mentioned four manners of the formation of dolomite in normal sea water, it proceeds under conditions when dispersed  $\text{MgCO}_3$  (remains of organisms of the calcium-magnesium group; basic salts of  $\text{MgCO}_3$ ) is already found in the sediments. Thus, the "absorption" of magnesium during diagenesis in Strakhov's review takes place only in two out of the four cases, and, as it was noted before (Teodorovich, 1950), one interaction of  $(\text{NH}_4)_2\text{CO}_3$  with magnesian salts does not usually effect a considerable dolomitization. As for the sea bottom currents, the enrichment of calcareous mud with  $\text{MgCO}_3$  was established in these cases long ago by A. Riviere (1939a and 1939b) on the basis of numerous experimental data.

For many years Strakhov has been showing his misunderstanding of our conception with respect to the Haidinger reaction. Yet its course for lesser salinities of sea water (small amounts of  $\text{MgSO}_4$ ) accompanied by the formation of dolomite, and for high salinities (considerable content of  $\text{MgSO}_4$  in the solution) in a single stage accompanied by development of magnesite, is described and elucidated in our article in 1950 (Teodorovich, pp. 72-73).

Surprising is his reference to the research of M. G. Valyashko (1952-1953) who, as he alleges, has established that the Haidinger reaction takes place only under conditions of saturation of the solution with  $\text{CaSO}_4$ . This contention has not in the least been proven, and it is rather refuted by Valyashko's data. Therefore, the assertion by N. M. Strakhov (1958, p. 13) That "the reaction of Haidinger is eliminated as a possible way of diagenetic formation of dolomite" is only his personal and, moreover, unfounded opinion.

But in reality M. G. Valyashko and G. K. Pelsh (and Nechaev, 1952, p. 185) in a report on the metamorphization of saturated calcium bicarbonate solutions point out that the formation of dolomite is definitely noted for a solution saturated with  $\text{MgCl}_2$ , though  $\text{CaCO}_3$ , that is formed at the expense of the decomposition of its bicarbonate, is predominant in the sediment. It has been ascertained for saturated solutions of the system  $\text{MgCl}_2$ - $\text{NaCl}$ - $\text{H}_2\text{O}$  with addition of a solution of calcium bicarbonate that "the permanent solid phases in this system are calcite and dolomite". As those authors believe, in cases of saturated chloride solutions compared with the metamorphization of sulfate solutions, "dolomite is formed here during a shorter treatment of solutions... How close to the point of pure  $\text{NaCl}$  begins the crystallization of dolomite... is difficult to tell exactly" (1953, p. 244). Regarding diluted solutions of the "sulfate type," it is pointed out that in many instances dolomite is formed here; its stability



(fields) have not been established and therefore the question of the formation of dolomite in these solutions requires further study (1953, p. 271, 274, etc.). That article generally says: "The question of the formation of dolomite in diluted solutions remains for the present unstudied" (1953, p. 271).

Strakhov's assertions that the formation of metasomatic dolomites is correlated with the stage of "weak" salinity of sea water approaching the saturation point with  $\text{CaSO}_4$  are unfounded, as it is well known that during diagenesis the formation of dolomite takes place in calcareous muds with a normal marine benthonic fauna. In those cases dolomitization was determined by an increased content of  $\text{MgCO}_3$  in muds and not by any noticeable general increase in salinity. But decreasing salinity usually resulted in the process of dolomitization by replacement according to the Haidinger reaction, or in the chemical precipitation of dolomite from the basin waters but only as a considerable admixture of  $\text{CaCO}_3$ . Strakhov (1956b, 1958) assumes that further dissolving and displacement of this admixture of the chemogenous dolomite in muds continued in Paleozoic time. However, the reason for displacement of chemogenous dolomite in the Paleozoic sediments characterized by a high  $\text{pCO}_2$  is obscure, as the  $\text{pCO}_2$  is usually higher in muds than in the atmosphere or in the  $\text{CO}_2$  of sea water occurring in equilibrium with the atmosphere. This is caused by an additional source of  $\text{CO}_2$  present here as decaying organic matter. Therefore, in carbonate muds of the Paleozoic only the spreading of dispersed grains of chemogenous dolomite could usually take place.

N. M. Strakhov (1958, p. 14) is unsound in his opinion that there are only two ways of absorption of magnesium by mud from bottom water, through the reduction of the sulfate ion and through the decomposition of organic matter. The calculations concerning the reduction of the sulfate ion to pyrite have no relation to the formation of dolomite connected with a lengthy absorption of  $\text{MgCO}_3$  by the mud from bottom sea water, since dolomite as the replacement by currents is formed in the uppermost zone (film) of the sediment, with pyrite in its lower zone (part), below the oxidation-reduction section.

Strakhov (1958, p. 14) writes arbitrarily about the "idea" of G. I. Teodorovich, "borrowed from Riviere" on the "warm-bottom currents which supposedly enrich the mud with magnesium". But, A. Riviere (1939a and 1939b) using as the basis "numerous experiments carried out in the Marine Laboratory of the French College in Concarneau during 1937, 1938 and 1939" ascertained that as a result of the contact of pure  $\text{CaCO}_3$  powder with slowly flowing sea water ( $t = 24^\circ$ ) for eleven months the carbonate composi-

tion proved to correspond to a proportion of  $\text{CaCO}_3 +$  about 8 percent  $\text{MgCO}_3$ ; this numerical ratio depends on conditions of the experiment. These are established facts and not "an idea of Riviere". If N. M. Strakhov's hypothetical calculations cannot provide explanations for the extraction of 8 percent  $\text{MgCO}_3$  from sea water, but explain only 1 percent dolomite formed in the manner indicated, this does not repudiate in any way the facts established by Riviere's experimental data. Strakhov (1958, p. 15) mentions that "... shallow seaside zones are generally characterized by high temperature water". However, the enrichment of calcareous mud with magnesium is determined not by the temperature of water but by the bottom currents. Therefore, his assertion that "... in following the idea of G. I. Teodorovich, one should have expected an inevitable, more or less considerable dolomitization of the near-shore carbonate muds," is groundless. Hence, Strakhov's general inference regarding the insignificant role of the diagenetic formation of dolomite is unsound, and, besides, the "mottled dolomites" themselves are the minority of diagenetic calcareous dolomitic rocks.

Hence it is clear that Strakhov's repudiation of the second point of view on the formation of dolomite and acceptance of the third, his own point of view, was made arbitrarily.

The third section of his article "The scheme of the formation of dolomitic rocks" contains inaccuracies in representing views of other researchers.

Here he sets forth his views on the genesis of "mottled metasomatic" dolomites which originate presumably when the salinity of sea water is considerable and which are due to regroupings in the mud during diagenesis. One cannot but note that in most cases dolomitic and calcareous-dolomitic replacement rocks are not mottled, and that the possibility of precipitation of dolomite in sediment as an admixture to  $\text{CaCO}_3$  definitely does not exclude other possible ways of the enrichment of the mud with magnesium, namely: as the result of accumulation of skeletons of organisms of the calcium-magnesium group; by absorption of magnesium by calcareous mud from the bottom currents; by way of precipitation of basic or hydrated carbonates of Mg; during the interaction of  $(\text{NH}_4)_2\text{CO}_3$  of the decayed organic matter with  $\text{MgCl}_2$  and  $\text{MgSO}_4$  of the muddy sea water. Most interesting here is that the forms of magnesium carbonate shifting in the mud will be others than  $\text{MgCO}_3$  which is part of the composition of sedimentary dolomite the grains of which will be usually only spreading.

N. M. Strakhov notes the development of mottled diagenetic dolomites by replacement in the Carboniferous period, particularly in the Upper Carboniferous with a bottom fauna of

typically marine organisms, the fusulines (Samarskaya Luka). These facts indicate that Strakhov's concept regarding the considerable increase of mineralization of sea water, i.e., its becoming saline (it is required for the precipitation of primary chemogenous dolomite in seas, which, according to Strakhov, is dissolved later and is shifted in the mud), contradicts his own observations under natural conditions.

Our interpretation of the replacement of the paragenesis of dolomite and calcite by that of calcite-magnesite with the increasing salinity of sea water is expounded incorrectly by Strakhov: 1) He attributes to us an opinion on the instability of dolomite with high concentrations of NaCl (1958, p. 17), while we always (Teodorovich, 1942, 1946b, 1950, 1955) stressed the contrary, i.e., the favorable aspect of the NaCl background in the formation of dolomite; 2) The fact of instability of dolomite with high concentrations of  $MgSO_4$  was established from experimental data (Nikolayev et al., 1941; Yanatyeva, 1949, 1950) and is beyond any doubt, though it is ignored by Strakhov; 3) Ever since 1951 N. M. Strakhov has been persistent in ignoring our interpretation of 1950 of the replacement of parageneses of dolomite and magnesite based on the two-stage course of the Haidinger reaction and on petrographic observations (Teodorovich, 1950).

For natural conditions, in 1946 (a, p. 137) we described the field of formation of dolomite: "In a number of minerals for different concentrations of water, dolomite often occupies... a place between calcite and calcium sulfate, partially overlapping the field of the later".

According to Strakhov (1951, 1958, p. 17), the reaction of Haidinger is only a magnesite-forming reaction; in his opinion, dolomite cannot originate in sea water saturated with  $CaSO_4$ .

In a series of articles and in his 1958 work he defends the concept that the saturation of a solution with  $CaSO_4$  at all times hinders the formation of dolomite. However, as has been shown by special physico-chemical investigations, the saturation of sea water with  $CaSO_4$  even at a low  $pCO_2$ , though hindering it, does not entirely prevent the formation of dolomite; as for increased and high  $pCO_2$  Strakhov's assertion is entirely unsound (Yanatyeva, 1955c).

In his 1958 work Strakhov (p. 18) writes about his ideas of the changes in carbonate parageneses as follows: "If the discussed considerations are correct we should have observed in gypsums and anhydrites not dolomite, but a mixture of calcite and magnesite. But in reality in anhydrites... dolomite occurs almost pure or with a large admixture of calcite, and only in a smaller number of cases the mixture of dolomite with calcite and magnesite is observed. A complete 'decomposition' of dolomite into

$CaCO_3$  and  $MgCO_3$  occurs in rocks much later when the salinity stages are higher, when NaCl and potassium salts are then crystallized". These factual correlations of parageneses are in complete conformity with our conception (Teodorovich, 1942, 1946b) and obviously contradict the scheme of N. M. Strakhov (1951, 1958) who attempts to prove "a delay" in the change of carbonate parageneses, that supposedly take place in nature, contrary to his scheme, by providing various suppositions piled one above another and difficult to verify.

Strakhov concludes his article with two statements:

1. "Following intensive coal and carbonate accumulations in Upper Paleozoic time the content of  $CO_2$  in the atmosphere greatly decreased," having effected a sharp decrease of the role of primary (sheet-like, according to Strakhov (1958, pp. 19-20), or sedimentary) dolomites in Mesozoic-Cenozoic time.

2. During a greater part or from the very beginning of the Mesozoic and in the Cenozoic only diagenetic dolomites by replacement ("sedimentary-diagenetic" according to Strakhov, 1951, 1956, 1958), were formed.

Similar contentions were advanced also by us in 1950 (Teodorovich, p. 77) and 1955 (pp. 91-92); moreover, we also noted a tendency for periodicity in the course of the formation of carbonates, and particularly of dolomites, in connection with the change of stages of regional tectonic cycles.

Our view on the periodicity and the general trend of the process of dolomite formation in the history of the Earth is elucidated in works of 1950 and 1955 (pp. 91-92). Consequently, the following comment by Strakhov is not clear: "As for the evolution of the formation of dolomite in the history of the Earth, G. I. Teodorovich has not attempted as yet to interpret these phenomena from the standpoint of his hypothesis" (1958, p. 12).

Strakhov writes: "Instead of direct precipitation of dolomite from water, the separate deposition of  $CaCO_3$  and of the basic salt of magnesium carbonate began at some time in the Proterozoic or Paleozoic (and perhaps, in some part of Mesozoic?), followed by the formation of dolomite as a mineral in the sediment" (1958, p. 21). This formulation reflects only the primary tendency of the evolution of the formation of dolomite, but it cannot be considered as a factually established general regularity. As was shown above, different primary occurrences of the formation of sedimentary dolomite could take place in the Paleozoic. Today too, there are instances of precipitation of primary dolomite observed in some places, but the principal modes of its formation in the bottom sediments



are different ones. An important factor in this process both in the Paleozoic and in our time is skeletal remains of organisms of the calcium-magnesian group.

There is no basis to consider all Mesozoic-Cenozoic microgranular dolomites of saline lagoons to be sediments of  $\text{CaCO}_3$  and basic salt of magnesium; the latter sediments precipitated for some reason in amounts equivalent or nearly equivalent for  $\text{CaCO}_3$  and  $\text{MgCO}_3$ . The genesis of these dolomites is much more diverse.

It is very interesting that M. G. Valyashko and G. K. Pelsh (and Nechayeva, 1952, p. 183), referred to by N. M. Strakhov on numerous occasions, write the following: "The obtaining of dolomite under conditions accepted in our experiments, i.e., under a pressure of  $\text{CO}_2$  equal to its partial pressure in the atmospheric air at  $T=25^\circ$ , is observed for the first time". In other words, Valyashko, on the basis of the experiments carried out, also points out the possibility of the formation of the primary chemogenous dolomite with the modern low  $p\text{CO}_2$  in the atmospheric air while Strakhov rejects possibility of its formation in modern times for the same reason.

However, primary formation of dolomite and dolomitization by replacement can take place also in modern times under conditions of underground water tables for their corresponding type and mineralization, or at an increased  $p\text{CO}_2$  in them. In addition, in modern surface reservoirs there are known occurrences of the primary chemogenous formation of dolomite. Besides Lake Balkhash (Sapozhnikov, 1951), we can point out, for instance, the Bay of the Kara-Bogaz-Gol. According to V. D. Poliakov, in 1940, in the area of the bay situated near the channel supplying the bay with water from the Caspian Sea, where the salinity of the water is lower, an accumulation of carbonates in the form of dolomite (alone or in admixture with calcite) took place in the mud; farther from the channel, with increasing mineralization, dolomite was found in mud together with gypsum, followed by an area of calcite-hydromagnesite-gypsum sediments covering the main part of the bottom of the bay (Teodorovich, 1955, p. 103).

The cited examples show the dependence of the formation of primary chemogenous dolomite in modern reservoirs on the type of water (the relative composition of dissolved salts). In fact, under conditions of sulfate-hydrocarbonate water of Lake Balkhash, chemogenous dolomite having an admixture of calcite is widely distributed in large areas of the lake (in deep parts) having a relatively increased mineralization and high values of  $\text{pH}>8.8-9$ . But in the chloride waters of the Bay of Kara-Bogaz-Gol the development of chemogenous

dolomite is limited; this is all the more understandable, since waters of the Aral-Caspian basin are richer in sulfates ( $\text{MgSO}_4$  and  $\text{CaSO}_4$ ) than waters of the normal marine type (Black Sea-Mediterranean). But Strakhov (1958, p. 21) sees only one reason that determines the possibility of formation of dolomite and it is "in the regimen of  $\text{CO}_2$  and the alkali reserve associated with it". However the alkali reserve is not determined by the  $\text{CO}_2$  regimen alone, but also by the type of waters, their mineralization and temperature. Therefore, there are several main factors in the formation of dolomite.

The discussion presented above as well as the earlier statements show quite clearly that in different cases dolomite can originate differently, and the main factors in the formation of dolomite are first of all the type of water, its mineralization and  $p\text{CO}_2$ , and also temperature and reaction of the medium; other factors seemingly are already less important (Teodorovich, 1942, 1950). Causes of the alteration of dolomite, such as its dedolomitization, varying solubility, etc., can differ from case to case. The clarification of the distribution of sedimentary dolomite in space and geologic time is closely connected with the manner of distribution of limestones. The knowledge of the process of development of carbonate rocks, in addition to corresponding data on other rock types, permits elucidation of the problem of regularities in the formation of sedimentary rocks and the genesis of both ore and non-ore sedimentary mineral deposits.

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# DOLOMITE AND SIDERITE OF THE MENILITE SERIES IN THE SOVIET CARPATHIANS<sup>1</sup>

by

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translated by Royer and Roger, Inc.

## ABSTRACT

The results of a mineralogic study of lenticular carbonate concretions in rocks of the menilite series are presented in this paper. These concretions have been found to consist mainly of iron dolomite with an admixture of pelitomorph calcite. There is about 10 to 30 percent of argillaceous matter, finely dispersed organic matter, quartz grains, and other materials in the rocks. The siderite concretions occur only with silicified argillite and layers of chalcedony in the menilite series. About 30 percent of the iron oxide is replaced by magnesium in the siderite, so that it can be called sideroplesite. The siderite concretions are silicified and contain chalcedony and pelitomorph calcite inclusions. They were formed in the bituminous menilite rocks during early diagenesis in the stage of redistribution of sedimentary matter. -- Auth.

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Lenticular, loaf-shaped, and sometimes broken dolomite seams occur among the black bituminous argillites in the menilite series (lower and middle Oligocene) in the Soviet Carpathians. For a long time nobody bothered to study these carbonate formations of the menilite rocks. It is therefore not by chance that both in field conditions and in scientific literature, geologists incorrectly term these dolomite siderite, sphaeroiderite, siderite marl, calcium-siderite formations, and so forth.

The first person to study these formations in detail in the Oligocene Carpathian deposits (in the transitional layers between the Krosno and menilite deposits) was the Polish geologist W. Narebski (1955). His investigations have added considerable lucidity to the terminology of carbonate formations among rocks of the Podmagur series, in the Gribovo and Krosno deposits, and so on. Narebski determined that the lenticular and loaf-shaped bodies were dolomite (and not siderites), composed of 3 to 10 percent FeO and 10 to 20 percent clay.

We also made a mineralogic study of 13 samples of lenticular and loaf-shaped carbonate bodies of the menilite series from various geologic sections of the Skibov zone of the Soviet Carpathians.

## DOLOMITE

Dolomites of the menilite series occur commonly in the forms of lenses and concretions of a rounded or extended elliptical shape, and also in the form of interrupted seams. The

dimensions of the lenses and loaf-like dolomite bodies range from several tenths of a centimeter to several meters. These formations are found among black, brown-black and dark gray bituminous argillites, which include, apart from argillaceous material, a great deal of finely dispersed organic material. The dolomite is usually in layers among these rocks. The black schistose bituminous argillite appears to flow around the dolomite lenses and form microfolds at the wedge-out points.

Microscopic investigation has established that the bulk of the lenticular bodies and concretions consist of a cryptocrystalline carbonate mass with high interference colors, feebly affecting polarized light. Dolomite with  $\text{FeCO}_3$  is marked by a light brown color.

The dolomite often contains single leaf injections of iron hydroxide of rounded or irregular diffuse shapes, pyrite grains and very frequently small quantities of finely dispersed organic matter. In most cases the pyrite is semi-decomposed and has formed iron hydroxide. The size of the pyrite grains does not exceed 0.06 mm.

Table 1 give the results of the chemical analysis of samples from lenses and loaf-shaped dolomite formations (the dissolved part was analyzed with heating up to 80° in 5 percent HCl); the water and  $\text{CO}_2$  were determined by a separate process. It is clear from the results of the chemical analysis that the proportion of carbonate in the dolomite lenses and concretions amounts to 70.09 to 93.61 percent, and only occasionally falls to 64.32 percent. The described dolomite formations contain very little  $\text{Fe}_2\text{O}_3$  (0.06 to 0.31 percent), which is a mechanical admixture forming from the iron hydroxides which occur when the pyrite decomposes.  $\text{Al}_2\text{O}_3$  is present in slightly greater quantities (1.16 to 3.40 percent). The more  $\text{FeO}_2$  there is in the rock, the less  $\text{Al}_2\text{O}_3$

<sup>1</sup>Translated from *Odolomitakh i sideritakh menilitovoy serii sovetskikh karpats*. Mineralogicheskoy sbornik, Lvovskogo geologicheskogo obshchestva, no. 13, 1959, p. 349-362.

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there is in its composition. The chemical analyses showed that in the more ferruginous dolomites, the insoluble residue is greater. This is partly due to the fact that fine pyrite inclusions are found more often in the lenses of more ferruginous dolomite.

If we discard the mechanical admixtures and

the indissoluble residue, and recalculate the carbonate content from the beginning, and then in terms of molecular percentage (table 2), it can be seen that our ferruginous dolomites in most cases have an admixture of free calcium carbonate. Only in two cases did the dolomite samples contain siderite impurities; this fact was brought out by examination of slides under the microscope. The comparison

TABLE 1. Chemical composition of ferruginous dolomite and siderite of the menilite series

| Number | Component                      | 24nd  | 2k    | 5k     | 28ch  | 47ch  | 516   | 17L    | 34nd  | 15ch  | 6sv     | 31nd  | 19     | 19a   |
|--------|--------------------------------|-------|-------|--------|-------|-------|-------|--------|-------|-------|---------|-------|--------|-------|
| 1      | Al <sub>2</sub> O <sub>3</sub> | 1.49  | 2.63  | 3.19   | 1.52  | 2.02  | 2.46  | 1.92   | 2.00  | 1.99  | 3.40    | 1.16  | 1.70   | 2.35  |
| 2      | Fe <sub>2</sub> O <sub>3</sub> | 0.07  | 0.19  | 0.16   | 0.34  | 0.22  | 0.18  | 0.28   | 0.31  | 0.11  | He 06H. | 0.06  | 0.28   | 0.32  |
| 3      | FeO                            | 3.58  | 4.73  | 2.26   | 4.95  | 5.30  | 7.42  | 7.41   | 6.41  | 7.72  | 1.59    | 2.67  | 13.52  | 14.02 |
| 4      | MnO                            | 0.10  | 0.10  | 0.04   | 0.10  | 0.06  | 0.24  | 0.19   | 0.38  | 0.31  | 0.06    | 0.14  | 0.47   | 0.83  |
| 5      | CaO                            | 23.12 | 24.44 | 23.33  | 29.17 | 24.64 | 18.06 | 26.41  | 24.22 | 24.58 | 29.82   | 40.82 | 1.61   | 1.95  |
| 6      | MgO                            | 15.64 | 11.96 | 11.90  | 13.67 | 11.85 | 9.58  | 10.82  | 12.60 | 11.48 | 14.52   | 7.74  | 2.88   | 3.51  |
| 7      | SO <sub>3</sub>                | 0.31  | 0.27  | 0.06   | 0.33  | 0.10  | 0.55  | 0.22   | 0.07  | 0.28  | 0.26    | 0.53  | 0.14   | 0.49  |
| 8      | CO <sub>2</sub>                | 39.52 | 34.95 | 32.54  | 38.54 | 35.38 | 29.02 | 36.62  | 36.40 | 36.48 | 40.20   | 42.24 | 12.68  | 13.82 |
| 9      | H <sub>2</sub> O               | 0.42  | 0.58  | 0.91   | 0.51  | 0.68  | 0.81  | 0.72   | 0.82  | 0.52  | 0.46    | 0.44  | 1.19   | 0.99  |
| 10     | Insoluble residue              | 15.37 | 19.64 | 25.87  | 10.54 | 19.67 | 31.54 | 16.17  | 16.85 | 15.85 | 9.61    | 3.98  | 66.07  | 62.34 |
|        | Total                          | 99.62 | 99.49 | 100.22 | 99.65 | 99.86 | 99.86 | 100.57 | 99.68 | 99.32 | 99.92   | 99.78 | 100.07 | 99.79 |

TABLE 2. Recalculation of chemical analyses of parts dissolved in HCl in terms of 100 percent of samples of lenticular formations of ferruginous dolomite and siderite

| Number | Name of Sample | FeO            |                    | MnO            |                    | CaO            |                    | MgO            |                    | CO <sub>2</sub> |                    | Molecular percentages |                   |                   |                   |
|--------|----------------|----------------|--------------------|----------------|--------------------|----------------|--------------------|----------------|--------------------|-----------------|--------------------|-----------------------|-------------------|-------------------|-------------------|
|        |                | weight percent | Molecular quantity | weight percent | Molecular quantity | weight percent | Molecular quantity | weight percent | Molecular quantity | weight percent  | Molecular quantity | CaCO <sub>3</sub>     | MgCO <sub>3</sub> | FeCO <sub>3</sub> | MnCO <sub>3</sub> |
| 1      | 24nd           | 4.37           | 061                | 0.12           | 0017               | 28.21          | 503                | 19.08          | 473                | 48.22           | 1038               | 48.45                 | 45.56             | 5.87              | 0.16              |
| 2      | 2k             | 6.20           | 086                | 0.13           | 002                | 32.09          | 572                | 15.70          | 389                | 45.88           | 1040               | 54.53                 | 37.08             | 8.20              | 0.19              |
| 3      | 5k             | 3.23           | 044                | 0.06           | —                  | 33.29          | 593                | 16.98          | 422                | 46.44           | 1055               | 56.00                 | 39.85             | 4.15              | —                 |
| 4      | 28ch           | 5.73           | 079                | 0.11           | 002                | 33.75          | 602                | 15.82          | 392                | 44.59           | 1014               | 56.00                 | 36.44             | 7.53              | 0.17              |
| 5      | 47ch           | 6.86           | 096                | 0.08           | 001                | 31.90          | 569                | 15.34          | 380                | 45.82           | 1040               | 54.40                 | 36.24             | 9.36              | 0.10              |
| 6      | 516            | 11.53          | 160                | 0.37           | 006                | 28.08          | 500                | 14.90          | 369                | 45.12           | 1026               | 48.31                 | 35.65             | 15.46             | 0.58              |
| 7      | 17L            | 9.10           | 127                | 0.24           | 003                | 32.42          | 577                | 13.28          | 329                | 44.96           | 1022               | 55.69                 | 31.76             | 12.26             | 0.29              |
| 8      | 34nd           | 8.01           | 111                | 0.47           | 007                | 30.28          | 539                | 15.74          | 390                | 45.50           | 1034               | 51.48                 | 37.25             | 10.60             | 0.67              |
| 9      | 15ch           | 9.58           | 134                | 0.38           | 006                | 30.53          | 544                | 14.25          | 353                | 45.26           | 1029               | 52.46                 | 34.09             | 12.92             | 0.53              |
| 10     | 6sv            | 1.84           | 025                | 0.07           | 001                | 34.60          | 616                | 16.85          | 418                | 46.64           | 1060               | 58.11                 | 39.43             | 2.36              | 0.10              |
| 11     | 31nd           | 2.85           | 040                | 0.15           | 002                | 43.60          | 778                | 8.27           | 206                | 45.13           | 1026               | 75.83                 | 20.07             | 3.90              | 0.20              |
| 12     | 19             | 43.40          | 603                | 1.50           | 021                | 5.16           | 092                | 9.24           | 254                | 40.70           | 925                | 9.48                  | 26.19             | 62.17             | 2.16              |
| 13     | 19a            | 41.08          | 570                | 2.43           | 034                | 5.71           | 102                | 10.29          | 256                | 40.49           | 920                | 10.60                 | 26.61             | 59.25             | 3.54              |

See footnotes pertaining to Tables 1 and 2 on the following page

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## Footnotes for Tables 1 and 2

- Sample 24nd - Bystritsa Nadvornyanskaya River (Pnev village), mnl<sub>1</sub>, loaf-like formation in black argillite 5 meters in length and 60 to 70 cm thick.
- Sample 2k - Stryy River (Korchin village), mnl<sub>2</sub>, loaf-like formation 5.5 to 6 meters long and 50 cm thick in layer of black non-carbonate argillite; layers of black argillite interbedded in sequence of gray and dark gray carbonate argillite with thin sandstone zones.
- Sample 5k - Selected 100 meters from sample 2k; lenticular concretions 1.8 meters in length and 70 cm thick in dark gray carbonate argillite, mnl<sub>2</sub>.
- Sample 28ch - Chechva River (south edge of Spas village) mnl<sub>1</sub>, lenticular carbonate formation 0.75 m long and up to 0.13 m thick. The top layer of lenticular carbonate contains black and brown bituminous argillite, and the bottom contains veins of the same argillite 10 cm thick which separates the lens from the sandstone seams.
- Sample 47ch - Chechva River (East Struten' village), loaf-like formations 4.5 m in length and 25 to 28 cm thick among black bituminous argillite, mnl<sub>3</sub>.
- Sample 516 - Chechva River (Sukhadol village), mnl<sub>1</sub>, interrupted seam 22 cm thick in black bituminous argillite.
- Sample 17L - Lyubizhnyy flow (Delyatin Town), mnl<sub>1</sub>, loaf-formation 11 m long and 20 to 25 cm thick in black bituminous argillite.
- Sample 34nd - Bystritsa Nadvornyanskaya River (Pasechnoye village), mnl<sub>1</sub>, lenticular formation 4 m long and up to 38 cm thick in black bituminous argillite.
- Sample 15ch - Chechva River (North of Lugi village), mnl<sub>1</sub>, lenticular formations 3 m long and 25 cm thick in black bituminous argillite.
- Sample 6sv - Stryy River (in front of Razgirche village), mnl<sub>2</sub>, loaf-like formation 3 m long and up to 60 cm thick in a gray and dark gray carbonaceous argillite.
- Sample 31nd - Bystritsa Nadvornyanskaya River (Pasichnoye village) mnl<sub>1</sub>, lens 36 x 60 cm in black bituminous argillite.
- Sample 19 - Chechva River (South part of Spas village), top layer mnl<sub>1</sub>, loaf-like formation 3 m long and up to 9 cm thick in greatly silicified black bituminous argillite with chalcedony veins.
- Sample 19a - Loaf-like formations 3.5 m long from the same place as Sample 19 in greatly silicified black argillite.

Chemical analyses carried out by B.N. Turkevich

TABLE 3. Chemical composition of argillaceous ferruginous dolomite in Oligocene deposits in Eastern Carpathians (Poland) according to W. Narebski

| Number | Oxides            | Podmagur Series | Gribovo deposits | Transitional deposits | Krosno layers |
|--------|-------------------|-----------------|------------------|-----------------------|---------------|
| 1      | FeO               | 8.63            | 5.26             | 3.35                  | 5.36          |
| 2      | MnO               | 0.79            | 0.39             | 0.07                  | 0.12          |
| 3      | MgO               | 9.94            | 14.31            | 14.35                 | 13.83         |
| 4      | CaO               | 23.26           | 32.93            | 28.96                 | 23.48         |
| 5      | CO <sub>2</sub>   | 36.31           | 44.75            | 39.40                 | 38.93         |
| 6      | Insoluble residue | 19.60           | 11.93            | 12.15                 | 15.59         |
|        | Total             | 98.53           | 99.57            | 98.28                 | 98.31         |
|        | Specific weight   | 2.79            | 2.79             | 2.80                  | 2.82          |

of the chemical analyses of the dolomites and ferruginous dolomites investigated by Narebski (table 3) convinces us that these dolomitic formations are very similar to each other in chemical composition.

The reconversion of the chemical composition (Sobolev, 1949) of the carbonate element in the ferruginous dolomite under consideration and those of the Oligocene deposits in the Polish

Carpathians (Narebski, 1955) has produced the crystallochemical formulas given in Table 4.

Thermal investigations of the carbonates of the menilite series have shown that most of them are anchorite (fig. 1). The heat curves for samples 24nd, 5k and 570 are typical of dolomite containing very little FeO, in view of which the endothermal effect between 815° and 830° is not very pronounced. The curves for



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TABLE 4. Mineral composition (dissolved carbonate in 5 percent HCl) of Lenticular and Loaf-like formations among menilite series rocks

| Number | Number of samples | Crystallochemical formula of prevailing mineral-ferruginous dolomite               | Admixture of other minerals of carbonate class |                  |
|--------|-------------------|--|--|------------------|
|        |                   |  | Calcite percent                                | Siderite percent |
| 1      | 24nd              | $\text{Ca}_{1.0}(\text{Mg}_{0.94}\text{Fe}_{0.06})[\text{CO}_3]_2$                 | —  | 3.18             |
| 2      | 2k                | $\text{Ca}_{1.0}(\text{Mg}_{0.82}\text{Fe}_{0.18})[\text{CO}_3]_2$                 | 9.0  | —                |
| 3      | 5k                | $\text{Ca}_{1.0}(\text{Mg}_{0.91}\text{Fe}_{0.19})[\text{CO}_3]_2$                 | 12.0   | —                |
| 4      | 28ch              | $\text{Ca}_{1.0}(\text{Mg}_{0.83}\text{Fe}_{0.16})[\text{CO}_3]_2$                 | 12.0   | —                |
| 5      | 47ch              | $\text{Ca}_{1.0}(\text{Mg}_{0.80}\text{Fe}_{0.20})[\text{CO}_3]_2$                 | 9.0  | —                |
| 6      | 516               | $\text{Ca}_{1.0}(\text{Mg}_{0.74}\text{Fe}_{0.25}\text{Mn}_{0.01})[\text{CO}_3]_2$ | —  | 3.38             |
| 7      | 17L               | $\text{Ca}_{1.0}(\text{Mg}_{0.72}\text{Fe}_{0.28})[\text{CO}_3]_2$                 | 11.4   | —                |
| 8      | 34nd              | $\text{Ca}_{1.0}(\text{Mg}_{0.77}\text{Fe}_{0.22}\text{Mn}_{0.01})[\text{CO}_3]_2$ | 3.0  | —                |
| 9      | 15ch              | $\text{Ca}_{1.0}(\text{Mg}_{0.72}\text{Fe}_{0.27}\text{Mn}_{0.01})[\text{CO}_3]_2$ | 5.2  | —                |
| 10     | 6sv               | $\text{Ca}_{1.0}(\text{Mg}_{0.94}\text{Fe}_{0.06})[\text{CO}_3]_2$                 | 16.2   | —                |
| 11     | 31nd              | $\text{Ca}_{1.0}(\text{Mg}_{0.83}\text{Fe}_{0.16})[\text{CO}_3]_2$                 | 51.6   | —                |

samples 2k, 571 and 28ch are usual for dolomites with more FeO than the first three samples (see table 1), hence they give a better indication of the small endothermal effect between 815° and 830°. The heat curves for samples 47ch, 516, 17L, 34nd and 15ch are characteristic of dolomites containing the greatest quantity of FeO, and are therefore very similar to the ankerite ones. Finally, the curves for the last three samples (6sv, 572 and 31nd) are typical of dolomites: they contain little FeO, and its dissociation is not recorded on the graphs. Sample 31nd is calcite with a small admixture of dolomite.

Generally speaking, it should be pointed out that all the graphs show two pronounced endothermal effects due to the dissociation  $\text{FeCO}_3\text{-NgCO}_3\text{-CaCO}_3$ . Here the first stage of dissociation between 770° and 830° is more complex, and the graph is divided into two stages by an exothermal rise, which is due to oxidation of the dissociating  $\text{FeCO}_3$  (Tsvetkov, 1949). Thus, together with the dissociation of  $\text{FeCO}_3$  there commences the oxidation of FeO to  $\text{Fe}_2\text{O}_3$ , which becomes predominant, and above 780° causes a small exothermal effect. After oxidation of the FeO, the dissociation of the  $\text{MgCO}_3$  continues, giving a second endothermal bend in the curve, but one considerably

smaller in magnitude. The third endothermal effect between 890° and 950° is the dissociation of the  $\text{CaCO}_3$ . It should be pointed out that in practically all the thermograms for the samples in question the endothermal effect due to a dissociation of  $\text{CaCO}_3$  is far greater in size than the endothermal effect between 770° and 790°. This is explained by the fact that practically all the samples of ferruginous dolomite have admixtures of free calcium carbonate (see table 2) to some extent or other, which on dissociation increases the corresponding endothermal effect of the dolomite. The small inclusions of siderite grains in the dolomite formations (samples 24nd and 516) are either very unpronounced on the graph, or not shown at all. For example, in the thermogram for sample 516, which is dolomite with an increased FeO content and grains of siderite, there is a small endothermal reduction from 490° to 610°, which changes to a very slight exothermal rise at 630°. The thermogram for sample 24nd, which is dolomite with a very small FeO content, does not show the siderite grains at all.

It should be said that in all cases the recording of the dissociation temperatures is greatly affected by admixtures of argillaceous material, finely dispersed organic matter, and

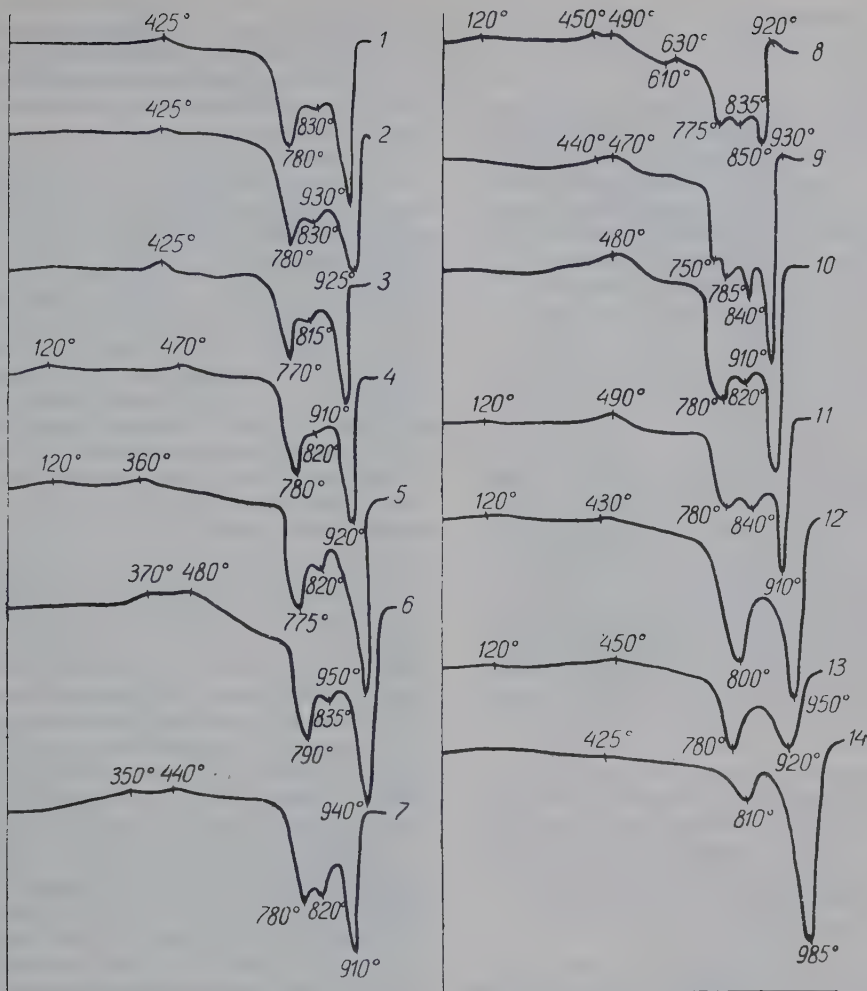


FIGURE 1. Heat curves for ferruginous dolomite of the menilite series

1 - Sample 24nd; 2 - Sample 2k; 3 - Sample 5k; 4 - Sample 570 (Chechva River, mnl<sub>3</sub>); 5 - Sample 571 (Chechva River, mnl<sub>3</sub>); 6 - Sample 22nd; 7 - Sample 47ch; 8 - Sample 516; 9 - Sample 171; 10 - Sample 34nd; 11 - Sample 15ch; 12 - Sample 16sv; 13 - Sample 575 (Chechva River mnl<sub>3</sub>); 14 - Sample 31nd.

so on. For purposes of comparison, Fig. 2 shows the heat curves for ankerite, after A. I. Tsvetkov (1949).

Some of the heat curves for the ferruginous dolomite described, have a slight exothermal effect at 120°, evidently corresponding to recrystallization of the iron hydroxide. The exothermal reactions between 425° and 450° are due to pyrite oxidation. The carbonate lenses containing, besides pyrite, a small quantity of organic matter, show two small exothermal effects over the temperature range 350° to 490° on the heat curves.

Thus, the detailed study of the carbonate lenses, concretions and seams has shown that in the overwhelming majority of cases they are

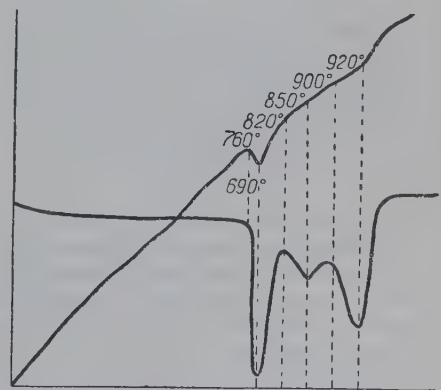


FIGURE 2. Heat curves for ankerite (after A. I. Tsvetkov, (1949))



ferruginous dolomite with the addition of argillaceous material, finely dispersed organic matter, and pyrite.

Field research and laboratory investigations of the carbonate formations of the menilite series show that when these formations are bedded in silty argillaceous and sandy argillaceous sections, they usually contain less argillaceous material. The amount of FeO in dolomite also depends on the nature of the rocks among which the dolomite lens or seam is situated. For example, more ferruginous dolomite is found in rocks with a large amount of finely dispersed material. In describing the conditions for the formation of lenses and loaf-like bodies of ferruginous dolomite, it should be pointed out that the strata were formed during the early diagenesis period — at the stage of redistribution of sedimentary matter. This is shown by their periodic stratification. Furthermore, since the schistosity in black argillite flowing round the lens is greatly disturbed, it is believed that these lenses, being hard bodies, existed at the time when the dehydration of argillaceous rocks and orogenic processes were taking place. The broken ferruginous dolomite seams may be a combination of several loaf-like formations all located at one strata level.

The investigations carried out suggest that in most cases during the formation of lenticular and loaf-like dolomite bodies, there was often insufficient dissolved magnesium salts in the sediments for complete dolomitization of the concretions; this is why the bodies almost always contain an admixture of free  $\text{CaCO}_3$ .

In other cases, when the amount of FeO was quite sufficient, a lenticular body formed from the ferruginous dolomite with a small inclusion of fine grains of ferrous carbonate. Dolomite with various ferrous iron contents was formed according to the composition of the sediment at the stage of its conversion into rock, and also according to the composition of the looser sediment covering it. The most ferruginous dolomite originated in the reducing medium in the thickening argillaceous sediments, rich in finely dispersed organic matter. Silty argillaceous sediments contain less finely dispersed organic matter, and also less ferrous iron. Consequently these rocks contain dolomite with the least amount of FeO, or no iron at all.

In certain cases we come across lenses consisting of pelitomorphous calcite with a small quantity of dolomite. These small lenses (0.5 to 1.5 meters) may have formed in the sediment in a more alkaline medium (pH=7.8 to 9) when there was insufficient magnesium and iron to replace the calcium.

Consequently, the conditions of the material in the sediment varied according to the nature

of the sediment: less-ferruginous or non-ferruginous dolomite with admixtures of  $\text{CaCO}_3$  formed in a strongly alkaline medium, while the more ferruginous dolomite with a very small admixture of  $\text{CaCO}_3$  or  $\text{FeCO}_3$  originated in a less alkaline medium.

From the genetic point of view, attention should be given also to the distribution of lenses and loaf-like dolomite bodies in rocks of the menilite series. For example, there definitely are dolomites among the black bituminous argillites. And even in the individual cases in which these formations are found in a silty argillaceous sequence or among sandstone seams, the lenses and loaf-like bodies are definitely separated, be it only by thin interlayers of black bituminous argillite. This can be explained by the fact that the best sediment for the formation of calcium and magnesium carbonate concretions was pelitic material, rich in finely dispersed organic matter. When it thickened, this sediment remained rather loose during the formation of the concretions; because of this our lenses and loaf-shaped bodies usually contain argillaceous material and finely dispersed organic matter, and sometimes single quartz grains, and so forth, to a greater or lesser degree. The greater the thickness of the black argillite layers containing the dolomite formations, the more ferruginous the dolomite is, and vice versa. The lenses and loaf-like formations among carbonate of the gray and dark gray argillite of the middle menilite series are represented by dolomite with the smallest amount of ferrous iron (1.54 to 2.26 percent). Here the argillite enclosing the dolomite lenses contain less carbonate than those in which there is no dolomite. This may be an indication that some of the argillaceous carbonates may well have gone into the formation of dolomite way back during the early diagenesis.

#### SIDERITE

In scientific literature dealing with the menilite series in the Carpathians, lenticular carbonate ferruginous dolomite formations are often termed siderite without any verification under laboratory conditions. Siderite occurs very rarely in the menilite series, however. According to our field research, these minerals are mainly associated with strongly silicified black argillite which contains chalcidony seams.

We noted siderite formations of a loaf-shape in the top layer of the lower menilite series, in a small chalcidony layer amid black, greatly silicified bituminous argillite at a deposit on the left bank of the Chechva River, between the villages of Lugi and Spas. The lengths of these bodies were 3 to 4 meters, their thickness was 7 to 9 cm, and they were in layers. On account of oxidation the siderite there was covered on top with iron hydroxide.

Transparent sections showed under the microscope that the bulk of the rock consists of a brown cryptocrystalline carbonate mass with high interference colors and an admixture of argillaceous material. Besides this material, the rock contains chalcedony impurities of an irregular, often diffuse shape, which from time to time cement the argillaceous carbonate mass. Through crossed nicol prisms, the sheaths of chalcedony have an undulating extinction; in most cases the size of the grains does not exceed 0.02 to 0.04 mm. The refractive indices of chalcedony vary from 1.531 to 1.539. The argillaceous carbonate mass also contains separate quartz grains of irregular isometric or extended shape with pronounced, unrolled edges. Quartz grains with uneven edges eaten away by the carbonate mass are commonly observed. The quartz extinction is normal. The grain size does not exceed 0.04 to 0.06 mm. The total amount of quartz and chalcedony is 3.5 to 4 percent. The amount of chalcedony and terrigenous quartz decreases from the periphery of the lens to the center. At the same time, the rock contains sections in which there is hardly any chalcedony or terrigenous quartz at all.

The argillaceous carbonate mass also contains single crystals and grain aggregates of pyrite. They usually consist of decomposed pyrite grains, and it is only in reflected light that separate points of nondecomposed mineral can be seen. The size of the aggregates is 0.06 to 0.08 mm, and sometimes 0.1 to 0.12 mm. The pyrite content in the lenses does not exceed 1 percent. The number of grains and grain aggregates increases with the number of chalcedony sheaths and quartz grains in the rocks.

Apart from the minerals enumerated, the argillaceous carbonate rock described contains single sheaths and smears of iron hydroxide. These are found particularly common at places where there are pyrite impurities. Iron hydroxide content ranges from single sheaths to 1.0 percent. Finally, single grains of green and bright green glauconite are often present in this rock. Their shape is isometric and the size does not exceed 0.02 mm.

Chemical analyses of the samples of loaf-like siderite bodies have shown that the soluble portion when heated to 70° or 80° in 5 percent HCl only amounts to 31.16 to 34.13 percent. The soluble portion (see table 1) contains 1.70 to 2.35 percent alumina, evidently originating from argillaceous material, and from 0.28 to 0.32 percent  $\text{Fe}_2\text{O}_3$ , which has been formed by free iron oxides which are contained in the rock in the form of fine sheaths and individual smears. Compared with the dolomite, siderite formations produce a very large soluble residue (62.34 to 66.07 percent). This may be due to the fact that they are considerably silicified and contain

much more terrigenous material.

If we discard the mechanical impurities and the soluble residue, and recalculate the carbonate in terms of 100 percent (see table 2), the carbonate contains 59.25 to 62.17 percent  $\text{FeCO}_3$ , 26.19 to 26.61 percent  $\text{MgCO}_3$  and 0.48 to 10.60 percent  $\text{CaCO}_3$ .

The recalculation of the carbonate in terms of the mineral formula (Sobolev, 1949) gives the following crystallochemical formulas:



The calcium carbonates were not taken into account during the recalculation since they are in all probability minerals (calcite) in the rock.

It follows from the results of the chemical and thermal analyses that in our siderite, the ferrous iron has been isomorphically replaced by magnesium and manganese. Judging from the amount of ferrous iron replaced by magnesium, the siderite in question is a variety called sideroplesites.

The heat curves for this sideroplesite (fig. 3),

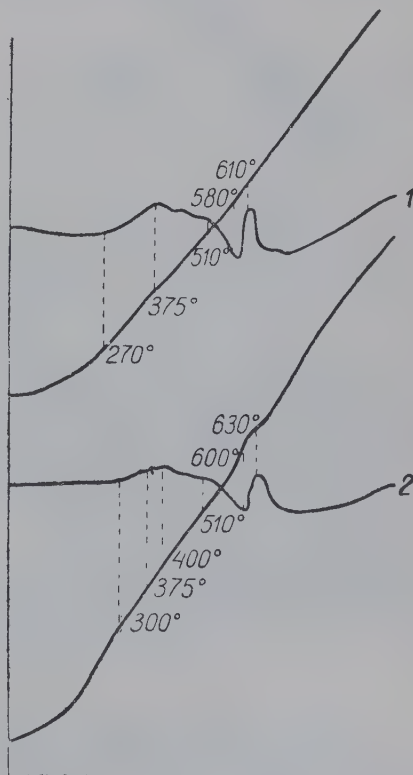


FIGURE 3. Heat curves for sideroplesite from the menilite series. 1 - Sample 19; 2 - Sample 19a.



compared with the curves for typical sideroplesite, show a weaker, but pronounced endothermal effect between 580° and 600°, which is due to the dissociation of  $\text{FeCO}_3$ . The exothermal effect between 600° and 630° is sharper, i.e., the exothermal reaction involved in the oxidation of  $\text{FeO}$  to  $\text{Fe}_2\text{O}_3$  is completed more rapidly than in thermograms free from mechanical admixtures of sideroplesite. All these exothermal characteristics are due to the fact that sideroplesite contains up to 66 percent argillaceous material, quartz, pyrite, finely dispersed organic matter, chalcedony, and so on, the presence of which definitely affects the dissociation temperature of  $\text{FeCO}_3$ . Both thermograms of the sideroplesite of the menilite series show a slight exothermal rise between 375° and 400°, which is due to the combustion of organic matter contained in the sideroplesite concretions. The admixtures of pelitomorphic calcium carbonate were not recorded on the thermograms in view of the fact that there is only very little of them in the concretions. Over the same temperature range there is also oxidation of the pyrite. For purposed of comparison, Fig. 4 shows the heat curves for sideroplesite, after A. I. Tsvetkov (1949).

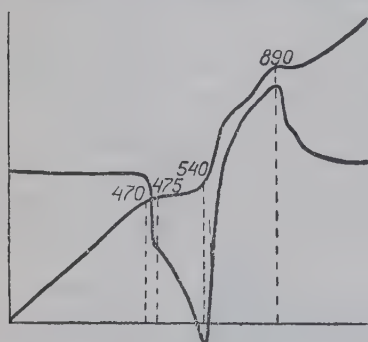


FIGURE 4. Heat curves for sideroplesite (after A. I. Tsvetkov)

Thus, the mineralogic investigation of the carbonate formations proved that the lenticular and loaf-like carbonate bodies of the menilite series are mainly ferruginous dolomite, and not siderite. Siderite is only found in the menilite series in strongly silicified black bituminous argillite with layers of chalcedony, i.e., it is formed in a slightly different geochemical medium than dolomite. Like the ferruginous dolomite, the siderite we discovered is also diagenetic, but had originated in a

more regenerative atmosphere in a neutral or slightly acid medium ( $\text{pH}=7.2$  to  $6.6$ ) in the presence of considerable amounts of free alumina in the sediment. We found dolomite with varying quantities of ferrous iron in the slightly alkaline medium with a  $\text{pH}$  value of  $7.2$  to  $7.8$ .

Still more alkaline conditions gave rise to lenticular bodies of  $\text{CaCO}_3$  and admixtures of dolomite or dolomitic concretions and considerable admixtures of  $\text{CaCO}_3$ . The presence in the sediment of a fairly large quantity of free silica undoubtedly promoted the silicification of the siderite bodies and the formation of chalcedony inclusions.

The author is very grateful to Professor Ye. K. Lazarenko under whose guidance the present work was completed.

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# MINERALOGY OF WEATHERED BASALT CRUST IN WEST VOLYNIA<sup>1</sup>

by

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translated by Royer and Roger, Inc.

## ABSTRACT

This article describes the weathered crust of extrusives of basic composition developed in West Volynia. Four different weathered crust zones are distinguished on the basis of the degree of mechanical disintegration and hypogene alteration of the rocks. The article gives a petrographic and mineralogic description of the individual zones as well as an account of the principal minerals in the hypogene complex. The reasons are given for the disproportionate amount of various flows in the weathered crust. Genesis of the weathered crust as a whole is discussed, and also the processes which determine the nature of the individual zones. The zonation of the layered silicates (celadonite, mountain leather, chlorite, and minerals of the montmorillonite group, and halloysite) and other hypogene minerals is mainly determined by the pH value of the solutions. The weathered basalt crust of West Volynia is a typical case of a crust formed over a long period on basic rocks in a warm and humid climate. --Auth.

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The weathered basalt crust in West Volynia has not been studied sufficiently. Scientific literature, mainly Polish, gives occasional references or macroscopic description of weathered basalt. It is only in M. Kamiński (1929) that we find a brief microscopic description of weathered basalt from Yanova Dolina. Information on the chemical composition of basalt affected by weathering from Berestovets can be found in Pfaffius (1886) and from Yanova Dolina in M. Kamiński. Malkowski (1951) also gives data from these authors and enumerates some hypogene minerals: iron and manganese hydroxides, and minerals with  $\text{SiO}_2$  composition. Finally, Weyberg (1935) mentions, in a short report, a "xilotile substance" composing the weathered crust on basalt columns in Berestovets. There are no other references to the weathered crust of West Volynia basalt.

## STRUCTURE OF WEATHERED CORE

According to the classification adopted at the present time (I. I. Ginzburg, 1957), the weathered crust of the Volynia basalt is a residual decomposition crust, since it consists mainly of minerals which have originated through the decomposition of the mother rock and have remained at the site of their formation. The infiltration and mechanical redeposition of carbonate matter from the chalk deposits covering the basalt is of much less importance.

The basalt weathered crust may be termed

open inasmuch as the uppermost part of the basalt cover is subjected to weathering, and the weathered crust is very near to the surface (the chalk, and Tertiary and Quaternary deposits covering the basalt in quarries does not exceed 1.5 to 2.0 m in thickness), and in a number of places are exposed at the surface. The rocks which undergo weathering are homogeneous in a chemical and petrographic respect, hence the basalt weathered crust in Volynia belongs to the group of simple weathered crusts.

It is much more difficult to solve the question of the extensiveness of the basalt weathered crust. It is found at all the places where basalt is quarried, although it is developed rather unevenly, even within one cover; it is therefore natural to assume that for the uppermost basalt covers which have the same bedding conditions and are covered by chalk or even more recent deposits, the weathered crust has an areal distribution. As far as can be judged from available material, the basalt which is interbedded with tuffaceous rocks and is not exposed at the sub-chalk surface, contains no trace of weathering.

The thickness of the weathered crust ranges, even within one cover, from 1.0-1.5 to 5-6 m, i. e., right down to the very bottom of the quarry (and possibly deeper).

On the basis of the degree of mechanical disintegration and the degree to which the rock is reworked by hypogenesis, the following four zones can be singled out in a basalt weathered crust (fig. 1):

1) Ocherous Loam Zone. This is an argillaceous material, powdery in the dry state, of brown, rust-colored or green-grey hue. The lower part contains small lumps of completely weathered basalt. Secondary mineral veins are fairly rare.

<sup>1</sup>Translated from K mineralogii kory vyvetrivaniya basaltov zapadnoy volyni: Mineralogicheskyy sbornik, Lvovskogo geologicheskogo obshchestva, no. 13, 1959, pp. 190-211.

<sup>2</sup>Lvov Institute of Mineral Geology of AN UkrSSR.



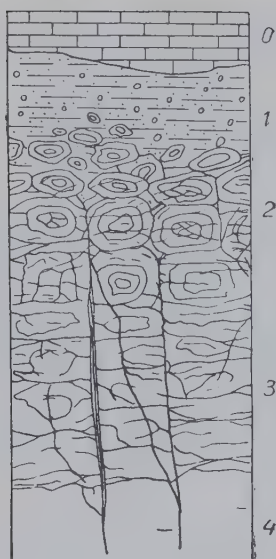


FIGURE 1. Diagram of profile of basalt weathered crust:

- 0 - chalk deposits of top layer;
- 1 - ocherous loam zone;
- 2 - zone of strongly decomposed rocks which have lost their original structure;
- 3 - zone of altered rocks which have partially retained the initial basalt structure;
- 4 - zone of basalt only slightly touched by weathering or completely unaltered.

2) Zone of greatly decomposed rocks which have lost their original structure.<sup>3</sup> This zone consists of fragments of intensively weathered basalt, which is expressed microscopically by its light coloring (light yellow or brown-grey and green hues). The fragments lie alongside each other and can be detached and broken by hand, while in the lower, transitional part of the zone, they can easily be broken with a hammer. In the sections which have exfoliation shell structures formed as a result of weathering, the basalt joining all the shells has been greatly changed right to the core. The upper part of the zone is made up of even smaller fragments and lumps of completely weathered basalt separated by the loose ocherous material of the upper zone.

3) Zone of altered rocks which have partly retained the structure of the original basalts. This zone is made up of intensively fractured rocks of a dark brown or dark green-grey color, compared with new basalt. They fracture much more easily than the latter, and with a dull sound. In the shell structure sections, the core

<sup>3</sup> This refers to the rock structure as seen under a microscope. The differences in the degree of alteration of the rock, observed under a microscope, nevertheless have a marked effect on the external appearance of the rock.

of the shells, particularly in the lower part of the zone, may consist of completely altered basalt.

The second and third zones are saturated with hypergene mineral deposits, the seams of which permeate the entire mass of rock.

4) The zone of basalts slightly affected by weathering or completely unchanged. In basalts without columnar structure (Dolgoye Pole), this zone is made up of rocks which do not show any outward signs of weathering, nor any detectable signs under the microscope. Along the exfoliation fractures hypergene minerals form veins which go deep into the fresh basalt.

In the covers where columnar structure was manifested (Yanova Dolina, Berestovets) we did not come across any basalts which were completely untouched by weathering. Each column within this zone retains its monolithic character, i.e., it is not subject to spalling or transverse fractures), is covered from top to bottom by a "shirt" of secondary mineral materials which can easily be separated from the column. Furthermore, each column, as is clear from a cross-section, has a clear zone 2 cm thick around the perimeter.

The variation in thickness of the weathered crust depends mainly on the following factors:

- 1) the presence or absence and nature of the columnar structure;
- 2) the presence or absence of weakened zones (of tectonic origin or connected with local manifestations of post-volcanic processes);
- 3) variations in the roof of the basalt cover due to its being washed nonuniformly.

The effect of columnar structure on the development of the weathered crust can easily be traced in the Berestovets basalt. The fractures between the columns, which sometimes reach 10 to 12 cm, serve as splendid channels for the circulation of vadose water. In the sections where the columns of basalt are of considerable thickness (from 0.5 - 0.7 to 1.0 m) and lie comparatively close to one another, the thickness of the upper three zones may be very small (0.5 to 1.0 m). But in fine columnar basalts (column diameter = 0.2 to 0.3 m) the weathering naturally takes place much more rapidly, because a large surface of rock is subjected to the influence of atmospheric agents and ground water simultaneously. Furthermore, fine columns are subject to transverse fracturing and exfoliation shell structure, which further increases the weathered surface. In sections with a fine columnar structure, the second and third zones impinge upon the fourth zone. Wherever the columns are bent and fan-shaped (Yanova Dolina), they are usually closely joined

to one another along a very uneven undulating surface; here the basalt is always weathered less than in sections with straight columns, similar to that of noncolumnar basalt.

Granulated zones and schist zones with a northwest strike, which are common in basalt, also act as channels for the penetration of the center of activity for surface water. According to the degree to which the basalt is weathered and to the abundance of hypogene minerals filling the fractures in these zones, even the lowest schist zones may be leveled to the second zone of the weathered crust, while alongside, at a distance of a half meter or only a few centimeters, there are monolithic columns hardly touched by weathering.

In Berestovets there are frequent blocks of tubular shape, composed of intensively fractured fine basalt, unsuitable for working, as a result of which the blocks are preserved in the form of curious "towers" which stick up in the middle of the quarry. The basalt composing the blocks is permeated with abundant deposits of hydrothermal minerals (calcite, zeolite, chalcedony, hematite and others). This supports Krajewski's (1936) and Malkovski's (1951) hypothesis that such formations in basalt ("kominy", i. e., tubes, as Malkovski calls them), observed in Yanova Dolina (in quarries no. 1 and no. 2, now flooded), where they covered both the upper and lower series of columns, are a kind of outlet for hot vapors and gases concentrated under enormous pressure to escape from under the basalt magma cover.

Rock which is permeated with veins and concentrations of hydrothermal minerals different in hardness and chemical composition represents an aggregate of great instability in relation to the physical and chemical factors of weathering. This explains the sharply increased weathering of such blocks compared with the surrounding normal columnar basalt.

Because of the presence of rock with increased weathering due to tectonically weakened zones and blocks of hydrothermally mineralized rock, the weathered crust of the Volynya basalt cannot be classed as the pronounced areal type, since in the given case a certain place belongs to linear and local types of weathering crust.

Variation in the thickness of the weathered crust due to changes in the roof can be observed in Dolgoye Pole. Here, for example, in the southeast corner of the quarry, the relative difference in height to the top layer at a distance 8 to 10 m is about 2 m. Although the total thickness of the basalt of the lower sections of the weathered crust is only 0.5 to 1.0 m, alongside, in the jutting part of the top layer, the thickness increases to 3.0 to 3.5 m, mainly on account of an increase in the second and third zones.

In the Mydzok Veliky basalts, which are directly covered with Quaternary deposits, there is no ochreous loam zone at all, and the second zone is also poorly developed; the top of the weathered crust here has apparently been washed away, in the same way that the chalk deposits were washed away. On the other hand, the lower 0.5 to 0.7 m of the cover, where there are concentrations of hydrothermal minerals accompanying the copper mineralization, are composed of very fine fragment of intensively weathered basalt saturated with deposits of hypogene minerals. There is also a weakened zone susceptible to weathering. Of great importance here are the tuffaceous rocks of the bottom, dense and deformed during basalt extrusions, which are impermeable to the circulation of surface water.

Thus, in the Mydzok basalts, the upper and lower parts of the covering undergo weathering, while the middle part is composed of completely fresh rock; consequently, the weathered crust of the closed type is developed locally here.

#### PETROGRAPHY AND MINERALOGIC CHARACTERISTICS OF THE WEATHERED CRUST

At the initial stages of weathering (third and partly fourth zones) the following transformations take place in basalt and are observable in the cross section. At first the glass breaks down and is replaced by a very fine-grained aggregate consisting mainly of chalcedony or opal and a chlorite substance; the grains of the ore mineral lose their sharp outlines and stains of iron hydroxides spread along the fractures in the adjoining minerals, sometimes assuming the appearance of wad-like leucoxene. The pyroxenes then begin to break down. A finely-dispersed yellowish or brown-green chlorite substance develops along the fractures in them usually with a mixture of nontronite, which gradually covers the whole pyroxene grain. An orange-brown fine-scaled or fine-lamellar iddingsite-like mineral with high index of refraction develops through the pyroxene. Since the decomposition of the pyroxene takes place at the same time as intensive oxidation of the ore minerals, the products replacing the pyroxene are usually strongly polluted with iron hydroxide and can only be discerned in sections with great difficulty.

The most stable components of the rock are plagioclases. Even when the weathering is advanced, they often remain completely fresh. In basalts of the third zone the changes in the plagioclase often only show up in an increased number of fractures and in a darkening in color.

Figure 2 shows the normal appearance of basalt at the initial stage of weathering.



mountain leather is one of the signs of incipient weathering of a rock.

In basalts with an amygdaloidal texture it is considerably more difficult to follow the changes due to weathering on account of the fine-grained texture of the rock and the degree to which it has been changed in the stage of autometamorphism. Nevertheless, the general course of the change in this kind of basalt is the same as in those with a uniformly fine-grained texture.

In the zone composed of intensively weathered basalt (second zone), the rock undergoes still greater changes, as can be seen from the sections. The glass is completely transformed into a finely-dispersed aggregate of chalcedony and chlorite; the pyroxene is replaced by a mixture of fine-scaled chlorite and calcite. Segregations of mountain leather, chlorite and celadonite are in turn intensively replaced by minerals of the montmorillonite group; they are all heavily stained with iron hydroxides. Under the microscope the most typical examples of weathered basalt of the lower part of the second zone consist of fractured, dull grains of plagioclase separated by brown or green-yellow segregations of argillaceous minerals and iron hydroxides. In the second zone there is intensive decomposition of the plagioclase, which frequently begins in the third zone; silicon is deposited in the process and a finely dispersed mixture of calcite is also formed. Argillaceous products of decomposition of the plagioclase are formed, which, due to the generally contaminable nature of weathered basalt by free iron oxides, are predominantly represented by nontronite, and partly by halloysite. When the plagioclase breaks down, the weathered basalt completely loses the structural pattern of an igneous rock. Small fragments and lumps of the top of the second zone are often composed of rounded, clotted chalcedony masses, cemented by argillaceous minerals and iron oxides (fig. 4).

FIGURE 2. Initial stage of decomposition of basalt (lower part of third zone).

Nicols parallel, x 12.

Plagioclase laths and large pyroxene grains have remained unaltered; everything else is replaced by the finely dispersed secondary minerals and is heavily stained with iron hydroxide.

However, there commonly are other types of changes in basalt. In sections in which there is intensive celadonitization, usually near hydrothermal mineral deposits, where there is not only a simple breakdown of the primary rock-forming minerals, but where infiltration is also developed (in particular, the introduction of potassium leached from the zeolites), the first to undergo decomposition are the pyroxene and glass, while the ore minerals remain unaltered; the mass of celadonite or celadonite-chlorite substance replacing the pyroxene and glass completely buries the fresh plagioclase laths and ore mineral segregations. The appearance in the rock of fine veins of chlorite-celadonite gel (fig. 3) or fine fibrous

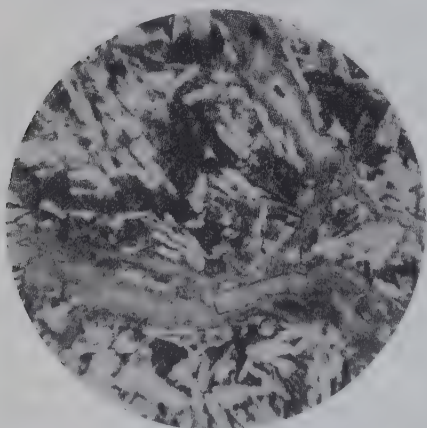


FIGURE 3. Seams of chlorite-celadonite composition in slightly weathered basalt.

Nicols parallel, x 34.

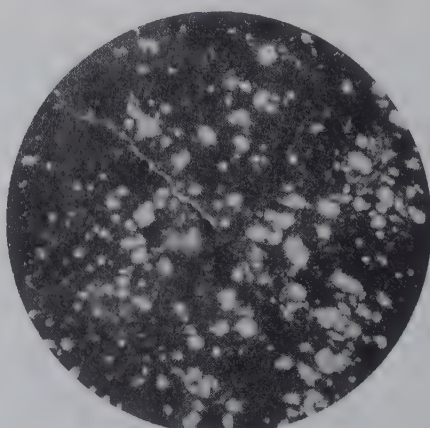


FIGURE 4. Final stage of decomposition of basalt (upper part of zone 2); chalcedony cemented with nontronite.

Nicols parallel, x 34.

TABLE 1. Chemical Composition of Weathered Basalt in West Volynya

| Analyses<br>Oxides             | 1      | 2     | 3     | 4     | 5      | 6      | 7     |
|--------------------------------|--------|-------|-------|-------|--------|--------|-------|
| SiO <sub>2</sub>               | 42.70  | 51.34 | 48.13 | 48.34 | 49.26  | 45.72  | 47.26 |
| TiO <sub>2</sub>               | 1.18   | 1.53  | 2.20  | 3.22  | 2.56   | 2.35   | 1.43  |
| Al <sub>2</sub> O <sub>3</sub> | 15.66  | 16.22 | 14.20 | 19.82 | 13.28  | 18.83  | 19.27 |
| Fe <sub>2</sub> O <sub>3</sub> | 8.10   | 13.52 | 8.14  | 9.47  | 3.29   | 14.27  | 10.62 |
| FeO                            | 5.29   | 0.42  | 7.05  | 0.42  | 10.70  | 0.76   | 1.48  |
| MnO                            | 0.19   | 0.10  | 0.17  | 0.08  | 0.18   | 1.15   | 0.10  |
| MgO                            | 7.69   | 2.86  | 5.50  | 2.09  | 6.41   | 4.27   | 1.35  |
| CaO                            | 5.82   | 3.00  | 9.47  | 6.21  | 9.31   | 5.24   | 5.11  |
| Na <sub>2</sub> O              | 3.32   | 2.09  | 0.76  | 0.16  | 2.44   | 0.79   | 1.88  |
| K <sub>2</sub> O               | 0.81   | 1.12  | 0.26  | 0.12  | 0.38   | 0.55   | 1.65  |
| P <sub>2</sub> O <sub>5</sub>  | 0.07   | 0.10  | 0.06  | 0.08  | —      | 0.07   | 0.20  |
| H <sub>2</sub> O <sup>—</sup>  | 1.26   | 5.00  | 2.43  | 5.96  | 0.86   | 4.74   | 5.33  |
| Unidentified                   | 3.89   | 3.65  | 1.23  | 3.53  | 1.77   | 2.82   |       |
| Total                          | 100.48 | 99.95 | 99.60 | 99.50 | 100.44 | 100.56 | 99.76 |

- 1 - Dolgoye Pole, amygdaloidal basalt untouched by weathering (fourth zone at distance of 4 meters from top of covering)  
 2 - Dolgoye Pole, weathered basalt (lower part of second zone, 1.3 meters from top of covering); the abnormal increase in the amount of silica and potassium compared with fresh basalt is due to the fact that most of the amygdules in this sample were filled with chalcedony and partially nontronitized celadonite  
 3 - Yanova Dolina, quarry #3, unaltered basalt  
 4 - Yanova Dolina, quarry #3, weathered basalt (lower part of second zone)  
 5 - Berestovets, quarry #9, unaltered basalt (after L. G. Bernadska, 1958)  
 6 - Berestovets, quarry #9, weathered basalt (upper part of third zone)  
 7 - Weathered basalt from Yanova Dolina (according to M. Kamiński, 1929)

An analysis of samples 1 through 4 and 6 was made at the author's request by the mineral chemistry laboratory of the AN of the U.S.S.R.

Compared with the fresh basalt, the weathered basalt of the second and third zones contains fewer alkalis, CaO, MgO, and silicon, and a greater quantity of aluminum oxide (table 1). The iron changes to the trivalent form almost completely, and the total amount is also somewhat reduced. The total content of volatile matter (water and carbonic acid) in the rock is increased.

The process of mechanical disintegration of a rock and its chemical reworking is completed in the ocherous loam zone. The study of this zone can only be made by means of mineralogic

methods or methods used for the investigation of sedimentary rocks.

The examination of fractions obtained during the mechanical analysis of test samples from this zone has shown that all fractions greater than 0.01 mm consist of fragments of primary minerals broken down to a certain extent (the plagioclase and ilmenite were best preserved but preservation of grains was very rare), and grains of neogenic chalcedony and opal. The fraction less than 0.001 mm consisting of samples of the sandy-argillaceous mass making up the ocherous loam zone was segregated.



The argillaceous minerals in the fourth zone are represented by iron montmorillonite, whose optical properties are similar to the nitronites from the other zones of the weathered crust, and the heat curves of which are normal for this group of minerals.

Here is a short description of the chief minerals in the hypergene complex.

The silicon oxides and hydroxides in the basalt weathered crust were represented by several varieties which differ in the degree of recrystallization and also in the presence or absence of water.

Granular quartz is made up of veins and drusy crusts on the walls of the fractures, concentrations of single crystals and fine-grained, irregular segregations among the loose products of weathering. It is often linked by gradual transition to chalcedony and quartz. Granular quartz is colorless, or sometimes greenish due to very finely-dispersed intergrowths of a chloritic material. The coloring in yellow and brown quartz is due to finely-dispersed iron oxides and in the case of dark gray quartz is due to a mixture of manganese hydroxides. A light violet quartz, described by S. S. Martynova (1955) is commonly found.

Metacolloidal quartz is sometimes present as an intermediate stage, between granular quartz and cryptocrystalline chalcedony, and is a product of the recrystallization of silica gel. Under crossed nicols it appear as an aggregate of fine-grained quartz, composed of isometric grains with mosaic extinction, and with one nicol it has a typical collomorphic structure (fig. 5). The refractive index of metacolloidal quartz is the same as that of ordinary granular quartz. Only some of the spherulites are marked by fan-shaped extinction and  $n = 1.548$  and  $\alpha = 1.541$ , i. e., they are nearer to chalcedony in their properties.

Chalcedony is the commonest of the minerals with the composition  $\text{SiO}_2$ . It forms numerous veins and nodules (pseudomorphs by replacement and coating) colored pink, lilac, yellow-brown, light blue, green and other shades by layers of a finely-dispersed mixture of various hypergene minerals. It also forms fine, clotted neogenic argillaceous minerals. The internal structure of the veins is usually fine-grained or transverse fibrous (fig. 6). Quartzite, a cryptocrystalline variety of silica with positive elongation is common. The refractive indices of of chalcedony vary in different segregations:  $n = 1.537 - 1.548$ ;  $\alpha = 1.530 - 1.542$ . Together with other oxides, chalcedony belongs to the group of hypergene jaspers<sup>4</sup>, whose veins are of considerable thickness (from 5 - 10 to 20 - 30 cm) and are often found in Berestovets and Yanova Dolina.

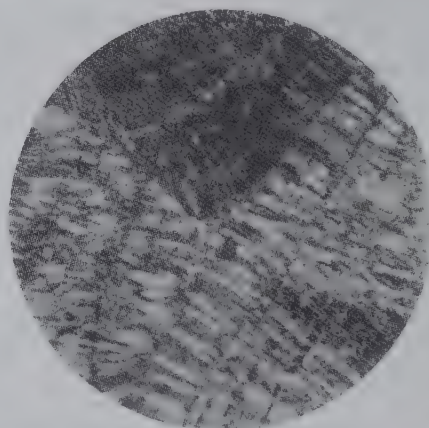


FIGURE 6. Transverse fibrous structure of chalcedony seams.  
Nicols crossed, x 34.

Opal cements the argillaceous mineral segregations or forms sinter, kidney-shaped or vesicular crusts on their surface; in the ocherous loam zone it is dispersed in the form of fine clotted segregations. Opal from sinter crusts is bluish in color, semi-transparent and has a waxy luster. Its segregations, in which a network of dessication fractures can be observed under one nicol, are usually isotropic. In the sections which do not have fractures, double refraction, caused by the stress occurring in the gels as a result of a reduction in volume during dehydration, is manifested by a fibrous structure with fan-shaped extinction and birefringence up to 0.005, and also in the appearance

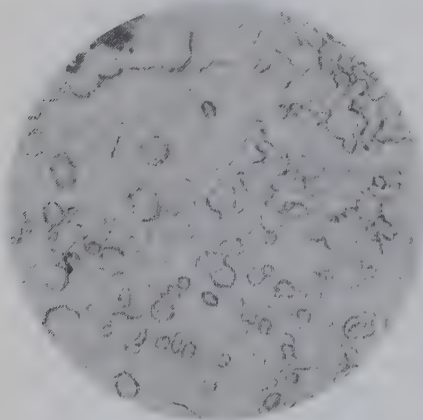


FIGURE 5. Metacolloidal quartz.  
Nicols parallel, x 70.

<sup>4</sup>Jasper is usually a dense siliceous sedimentary rock, but the term is frequently applied to formations consisting of chalcedony with a large amount of impurities, regardless of the origin of the formation (Lazarenko, 1951; Winchell, 1953).

of characteristic fine rings with quartz birefringence (fig. 7). In opal the index of refraction ranges in different segregations from 1.433 to 1.450; during weathering and partial dehydration it increases up to 1.460 to 1.473.

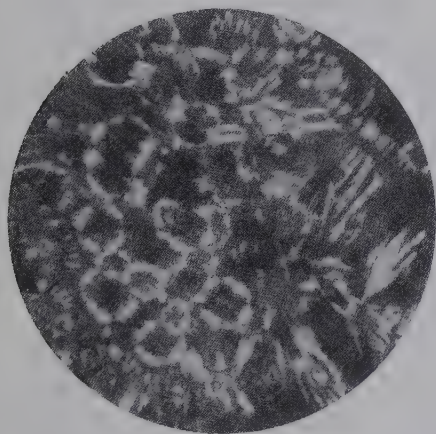


FIGURE 7. Double refraction through stress in opal.  
Nicol's crossed,  $\times 34$

Iron hydroxides are extremely common in the basalt weathered crust. Together with chalcedony, iron ochers form a solid envelope around the basalt columns, and make up part of the large hypogene mineral veins; iron hydroxide segregations permeate the entire weathered basalt and also play an important part in composing the ochrous loam zone. The color of iron hydroxide varies from light ocher-yellow to dark red-brown. The form of the segregations ranges from loose, dusty masses to crusts with a 3 to 3.5 hardness and a resinous luster. Segregations of structural limonite, which have evidently formed during the decomposition of hydrothermal pyrite and bornite, are also present.

Manganese hydroxides form concentrations of loose masses of a brown or blue-black color along the walls of fractures in faded weathered basalt. An addition of manganese oxide compounds is usual in iron ochers (on account of the mutual coagulation of oppositely-charged iron hydroxide and manganese gels), and also in hypogene calcite.

In Mydzok Velikiy and Berestovets there are large concentrations of wad formed through the decomposition of manganese-bearing hydrothermal calcite. Wad from Mydzok takes the form of monomineral nodules up to 4 to 5 cm in diameter, which are very fragile, porous, extremely light, and have dessication cracks. The whole of the manganese is contained in the nodular substance in oxide form, which brings the given variety of manganese oxide nearer to vernadite -  $\text{MnO}_2 \cdot n\text{H}_2\text{O}$  ( $n = 0.4$  to  $1.0$ ).

Mountain leather is widespread in the lower part of the basalt weathered crust (Shashkina, 1959).

Celadonite is also widely developed in the Volynya basalt, where it originated through low-temperature hydrothermal processes, and also at the initial stages of the basalt weathering. We describe below hypogene celadonite, which is far more widespread than the hydrothermal type.

References to celadonite from the Volynya basalts are given in the works of V. Blyumel (1867), A. P. Karpinsky (1873), M. Kamiński (1929), and S. P. Malkowski (1951); Ye. K. Lazarenko (1956) has studied the Berestovets celadonite.

In weathered basalt, predominantly in the third and fourth zones, celadonite forms large veins, up to 10 to 12 cm in thickness (monomineral veins or veins with mountain leather and calcite, iron oxides and other hypogene minerals). The shape of the celadonite segregation varies from thick, stony formations to loose, powdery masses. It forms what appear to be under the microscope entangled fibrous aggregates, and ingrowths of fine acicular crystals growing from one nucleus, and fine-scaled concentrations; very typical of celadonite are vermicular, bent netted formations (fig. 8).

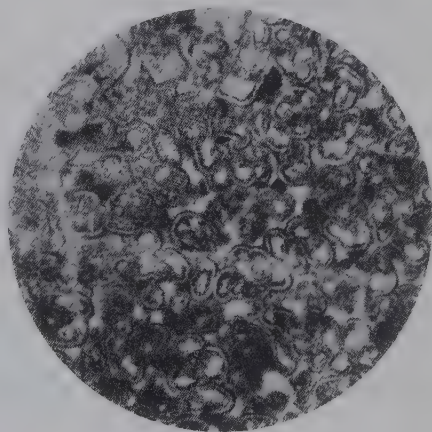


FIGURE 8. Meshed structure of celadonite segregations.  
Nicol's parallel,  $\times 34$

In the dry state the mineral is colored various shades of green, light or dark blue; when wetted with water or immersion liquids, the light blue and dark blue shades become fainter, while the green color is intensified. The elongation of the celadonite needles is positive and the extinction is straight;  $\gamma = 1.627$  to  $1.642$ ;  $\alpha = 1.600$  to  $1.615$ ;  $\gamma - \alpha = 0.025$  to  $0.030$ ; there is intensive pleochroism according to the pattern  $\gamma > \beta > \alpha$ .



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TABLE 2. Chemical Composition of Celadonite from Volynya Basalt

| Analyses<br>Oxides             | 1            | 2      | 3      | 4            | 5      | 6      | 7     |       |
|--------------------------------|--------------|--------|--------|--------------|--------|--------|-------|-------|
|                                |              |        |        |              |        |        | From  | To    |
| SiO <sub>2</sub>               | 54.49        | 53.54  | 53.55  | 56.88        | 49.60  | 52.58  | 49.85 | 57.72 |
| TiO <sub>2</sub>               | Trace        | 0.09   | 0.21   | 0.20         | 0.65   | 0.15   | —     | —     |
| Al <sub>2</sub> O <sub>3</sub> | 12.60        | 12.02  | 4.92   | 11.06        | 3.55   | 6.77   | 0.79  | 10.90 |
| Fe <sub>2</sub> O <sub>3</sub> | 9.52         | 8.21   | 12.56  | 10.68        | 20.02  | 20.07  | 6.95  | 20.46 |
| FeO                            | 2.95         | 3.21   | 3.78   | 2.45         | 2.39   | 3.33   | 2.00  | 5.37  |
| MnO                            | 0.05         | Trace  | 0.08   | Trace        | 0.08   | Trace  | —     | —     |
| MgO                            | 6.24         | 6.99   | 8.52   | 6.62         | 5.09   | 6.22   | 3.84  | 9.32  |
| CaO                            | 0.65         | 0.49   | 1.02   | 0.94         | 2.13   | 0.91   | следы | 3.10  |
| Na <sub>2</sub> O              | 0.48         | 0.07   | 0.62   | 0.19         | 0.34   | 0.05   | следы | 3.34  |
| K <sub>2</sub> O               | 7.41         | 8.43   | 6.03   | 3.54         | 3.75   | 3.33   | 3.33  | 10.03 |
| P <sub>2</sub> O <sub>5</sub>  | Undetermined |        | 0.22   | Undetermined | 0.22   | —      | —     | —     |
| H <sub>2</sub> O—              | 1.60         | 2.35   | 3.54   | 2.29         | 7.33   | 6.75   | 4.88  | 12.52 |
| H <sub>2</sub> O+              | 3.59         | 4.69   | 5.25   | 4.69         | 5.11   |        |       |       |
| Total                          | 99.58        | 100.09 | 100.20 | 99.54        | 100.26 | 100.16 | —     | —     |

Crystochemical formulas:

1.  $(K_{0.65}Na_{0.06}Ca_{0.05})_{0.71}(Mg_{0.63}Fe_{0.17}Fe_{0.49}Al_{0.78})_{2.07}(OH)_2 \left[ \frac{Al_{0.24}Si_{3.76}O_{10}}{Al_{0.25}Si_{3.75}O_{10}} \right] \cdot 0.19H_2O$
2.  $(K_{0.75}Na_{0.02}Ca_{0.03})_{0.80}(Mg_{0.74}Fe_{0.18}Fe_{0.42}Al_{0.75})_{2.09}(OH)_2 \left[ \frac{Al_{0.24}Si_{3.76}O_{10}}{Al_{0.25}Si_{3.75}O_{10}} \right] \cdot 0.65H_2O$
3.  $(K_{0.56}Na_{0.08}Ca_{0.08})_{0.72}(Mg_{0.92}Fe_{0.23}Fe_{0.69}Al_{0.32})_{2.16}(OH)_2 \left[ \frac{Al_{0.10}Si_{3.90}O_{10}}{Al_{0.11}Ti_{0.01}Si_{3.88}O_{10}} \right] \cdot 1.1H_2O$
4.  $(K_{0.30}Na_{0.01}Ca_{0.07})_{0.38}(Mg_{0.67}Fe_{0.14}Fe_{0.55}Al_{0.78})_{2.14}(OH)_2 \left[ \frac{Al_{0.11}Ti_{0.01}Si_{3.88}O_{10}}{Al_{0.16}Ti_{0.03}Si_{3.81}O_{10}} \right] \cdot 0.59H_2O$
5.  $(K_{0.36}Na_{0.04}Ca_{0.17})_{0.57}(Mg_{0.59}Fe_{0.15}Fe_{1.16}Al_{0.16})_{2.06}(OH)_2 \left[ \frac{Al_{0.16}Ti_{0.03}Si_{3.81}O_{10}}{Al_{0.27}Ti_{0.01}Si_{3.72}O_{10}} \right] \cdot 2.18H_2O$
6.  $(K_{0.30}Na_{0.01}Ca_{0.07})_{0.38}(Mg_{0.65}Fe_{0.22}Fe_{1.06}Al_{0.29})_{2.22}(OH)_2 \left[ \frac{Al_{0.27}Ti_{0.01}Si_{3.72}O_{10}}{Al_{0.27}Ti_{0.01}Si_{3.72}O_{10}} \right] \cdot 0.64H_2O$

1 - Sample 485/1 Dolgoye Pole; 2 - Sample 513A, Dolgoye Pole;

3 - Sample 513/2 Dolgoye Pole; 4 - Sample 162b, Berestovets;

5 - Sample 511, Dolgoye Pole, partially nontronitized celadonite;

6 - celadonite from Berestovets (according to M. Kamiński, 1929)

7 - variations in chemical composition of celadonite (according to Ye. K. Lazarenko, 1956)

Analyses of 1, 2, and 4 were made at the author's request by the Mineral Chemistry Laboratory of the AN U.S.S.R. samples 513/2 and 511 were analyzed by B.M. Turkevich, scientist of the VNIGNI.

Table 2 gives the results of a chemical analysis of types of celadonite from the Volynya basalt, and Figure 9 gives their heat curves.

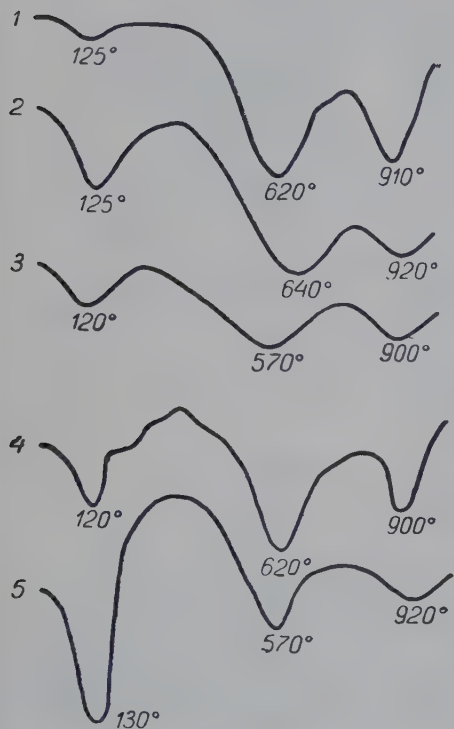


FIGURE 9. Differential heat curves for celadonite from Volynya basalt.

- 1 - Sample 485/1, Dolgoye Pole;
- 2 - Sample 513a, Dolgoye Pole;
- 3 - Sample 162b, Berestovets;
- 4 - Celadonite from Berestovets (after Ye. K. Lazarenko)
- 5 - Sample 511, Dolgoye Pole; partially nontronitized celadonite.

X-ray diffraction patterns of celadonite, which has the most perfect structure of hydro-micas, is marked by sharpness of lines and complete coincidence in magnitude of the interplanar distances in all samples examined.

Celadonite is formed in the weathered crust in the following two ways:

- 1) by replacement of earlier deposited minerals (this method of formation is of secondary importance);
- 2) by direct sedimentation from a colloidal solution of complex composition (figure 10).

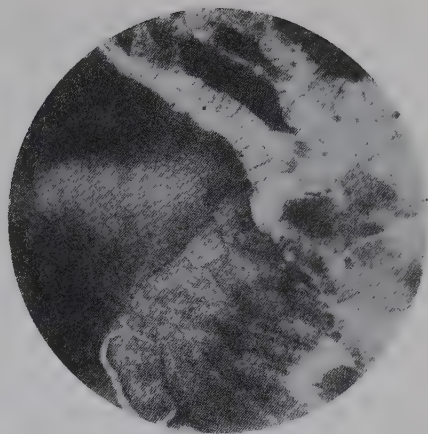


FIGURE 10. Metacolloidal celadonite (light) fills fractures in metacolloidal formation of heterogeneous composition (celadonite plus iron hydroxide).  
Nicol's parallel,  $\times 34$ .

Chlorite is made up of numerous fine gel-shaped and finely-dispersed (more rarely, fined-scaled) segregations and veins dispersed in the mass of unaltered basalt. The coloring of chlorite is yellowish-green;  $\beta = 1.582$  to  $1.605$ , and the interference shades are grey.

In the mineral representing the intermediate period of stage-by-stage weathering of chlorite-jefferisite,  $\beta$  drops to  $1.560 \pm 0.010$ ;  $\alpha = 1.542 \pm 0.003$ ; the birefringence is increased to  $0.020$  to  $0.025$ , and sometimes to  $0.035$ ; the green scales become greyish and bluish.

Montmorillonite. The minerals of the montmorillonite group in the basalt belong to the commonest hypogene formations, and are chiefly represented by varieties of iron-nonttronite, the segregations of which are extremely varied, and range from loose, powdery masses to dense argillite-like veins. There are also fine-scaled aggregates with high viscosity, glass-like masses of solidified gel, and so forth. These segregations are various shades of brown, yellow and green approaching white. Under the microscope the nonttronite looks like scaly, radially foliated, entangled, fibrous aggregates, clots of finely-dispersed matter, etc. The optical properties of this group of minerals are highly variable: ranges from  $1.642$  to  $1.510$ . The differential heat curves for nitronite are given in Figure 11.

X-ray investigation has shown that the minerals of the montmorillonite group in the hypogene complex under investigation are represented, apart from varieties of iron, basically by magnesium types, which tallies completely with the chemical composition of the initial rocks.



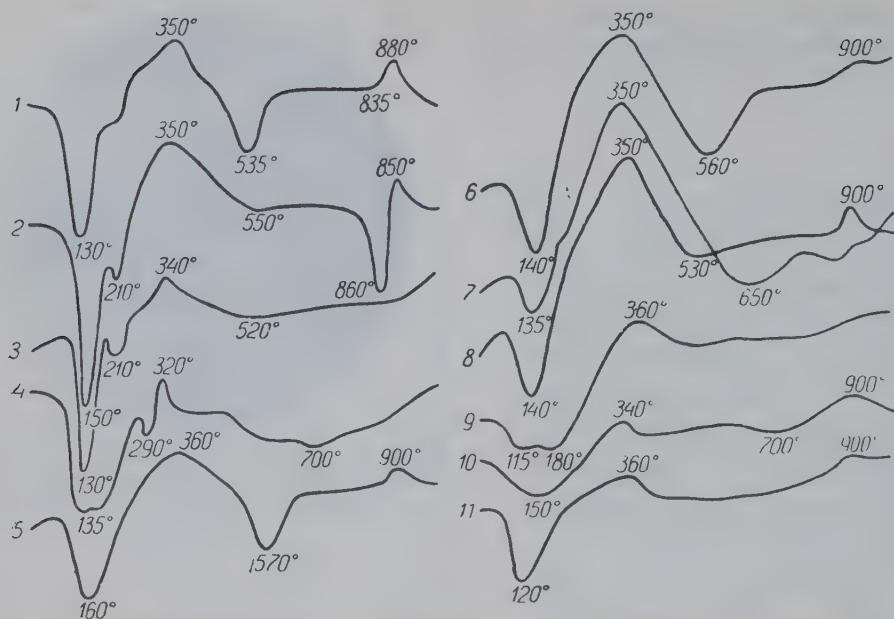


FIGURE 11. Differential heat curve for nontronite from Volynya basalt.

Halloysite predominates in rocks of the second zone, since it is formed through the decomposition of plagioclase. On account of the small grain size of the plagioclase, the segregations are very fine and become lost in the mass of other secondary minerals. Concentrations of halloysite form in places where the fragments of basalt, in which the plagioclase is still fresh but other minerals are completely decomposed, come under particular weathering conditions, i. e., where they are isolated in the envelope of neogenic chalcedony. Halloysite forms white, finely-dispersed clots.

Carbonates are common in the weathered crust and take the form of fine-grained veins and drusy crusts. The shape of their crystals is elongated-scalenohedric and acicular. The carbonates are represented by calcite and dolomite.  $\gamma = 1.672$  to  $1.690$ .

#### GENESIS OF THE WEATHERED CRUST

For the purpose of determining the genesis of the weathered crust of Volynya basalt, we calculated the pH value<sup>5</sup> of the previously described argillaceous fractions, and also that of the main

hypergene minerals (table 3).

In the specimens examined, the pH value ranged from 7.0 to 9.0. A value higher than 8 was observed in calcite, celadonite and those fractions from the ochreous loam zone which contain an addition of incompletely nontronitized celadonite; in montmorillonite-nontronite the pH value ranged from 7.0 to 7.9.

The mechanism of the formation of the weathered crust of basalt occurred in a slightly alkaline medium. Knowing the pH value of various minerals in the weathered crust from our own and other data (Karyukina, 1953), and comparing the abundance of these minerals in various zones, we came to the conclusion that in the lower part of the weathered crust (third and fourth zones, and also the bottom of the second zone), at the initial stages of alterations of the basalt, the medium was more alkaline; but in the upper part of the crust the pH value of the solutions was lower and the medium was closer to neutral.

The increased alkalinity of the solutions circulating in slightly weathered rock is due to the fact that it is precisely in these rocks at the initial stage of weathering than there is leaching from the primary silicates of the most mobile components:  $K_2O$ ,  $Na_2O$  and  $CaO$ , and also  $MgO$  and  $FeO$ . The considerable alkalinity of the solutions increases the solubility of such comparatively nonmobile oxides as  $SiO_2$  and, particularly,  $Al_2O_3$ .

<sup>5</sup>The author determined the pH value in a 20 percent suspension of the mineral with a PEP-pH-2A portable pH meter. To prepare the suspension, the ground mineral is passed through an 0.1 mm sieve; the pH value is measured 24 hours after the suspension is prepared.

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TABLE 3. Calculation of pH Value of Suspensions of Different Formations from Volynya Basalt Weathered Crust

| Number  | Number of sample and place from which taken | Definition of Sample   | Concentration of suspension in percent | pH        |
|---|---|--|--|-----------|
| 1   | 510, Dolgoye Pole                           | Mountain leather   | 5*                                     | 7.9       |
| 2   | 513a Dolgoye Pole                           | Celadonite   | 20                                     | 8.0       |
| 3   | 162b, Berestovets                           | Celadonite   | 20                                     | 8.2 - 7.8 |
| 4   | 162a, Berestovets                           | Nontronitized celadonite   | 20                                     | 7.4       |
| 5   | 511, Dolgoye Pole                           | Nontronitized celadonite   | 20                                     | 7.5       |
| 6   | 467, Dolgoye Pole                           | Hypergene calcite  | 20                                     | 8.5       |
| 7   | 135, Yanova Dolina                          | Hypergene calcite  | 20                                     | 9.0       |
| 8   | 425, Mydzk Velikiy                          | Wad from monomineral nodules   | 20                                     | 7.7       |
| 9   | 690, Berestovets                            | Nontronite   | 20                                     | 7.5       |
| 10  | 540, Dolgoye Pole                           | Montmorillonite  | 20                                     | 7.8       |
| Fractions smaller than 0.001 mm from ochreous loam ** |   |  |  |           |
| 11  | 548, Dolgoye Pole                           | Lumps of soft, dusty gray-yellow clay; clay fraction represented by nontronite   | 20                                     | 7.8       |
| 12  | 471, Dolgoye Pole                           | Powdery light-brown sandy-argillaceous mass with greenish tinge; clay fraction represented by nontronite with minor admixture of chloritic-celadonitic matter                                | 20                                     | 7.5       |
| 13  | 554 Dolgoye Pole [?]                        | Dark yellow loose, lumpy clay with sandy admixture; clay fraction represented by nontronite with small admixture of iron hydroxide   | 20                                     | 7.0       |
| 14  | 601, Berestovets                            | Light brown sandy-argillaceous loose mass; clay fraction represented by nontronite with small admixture of chloritic-celadonitic matter  | 20                                     | 7.8       |
| 15  | 176, Berestovets                            | Fragments of light gray green tinged intensively weathered basalt from top of second zone; clay fraction represented by nontronite with considerable mixture of chloritic-celadonitic matter | 20                                     | 8.0       |
| 16  | 642, Berestovets                            | Dusty clay of rusty bright color; clay fraction is nontronite with considerable admixture of chloritic-celadonitic matter is possible.   | 20                                     | 7.9       |
| 17  | 112, Yanova Dolina                          | Powdery green-brown sandy-argillaceous mass; clay fraction is nontronite.  | 20                                     | 7.7       |

\* A higher concentration for mountain leather can only be attained with great difficulty, because when the mineral is ground down to 0.1 mm, it swells and absorbs all the water. According to T. S. Berlin (see M. F. Vikulova et al, 1957), in argillaceous minerals considerable variation in the pH value with the suspension concentration and time of contact between the liquid and solid phases has not been observed.

\*\* We give descriptions of the initial material when the fractions were obtained.



The solubility of silica depends on its reaction with the medium (figure 12), considerably increasing in the area of low and high pH values, and falling sharply in a neutral medium.

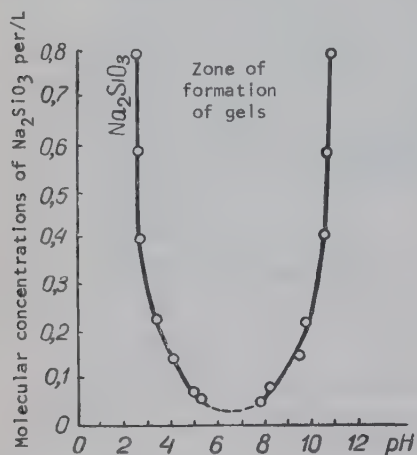


FIGURE 12. Solubility of  $\text{Na}_2\text{SiO}_3$  as function of pH value (according to Ray and Gängely; quoted from I. I. Ginzburg and I. A. Rukavishnikova, 1951)

According to data obtained by Korrens and Engelhardt (Ginzburg and Rukavishnikova, 1951), during silicate decomposition a small amount of  $\text{SiO}_2$  changes to distilled water, a greater amount of silica is taken away by acid, and the maximum amount by alkaline water. The solubility of alumina also depends on the pH value of the medium. Minimal solubility of  $\text{Al}_2\text{O}_3$  is observed between pH = 6.7 and 7.0; at pH = 7.55 the solubility become appreciable (fig. 13).

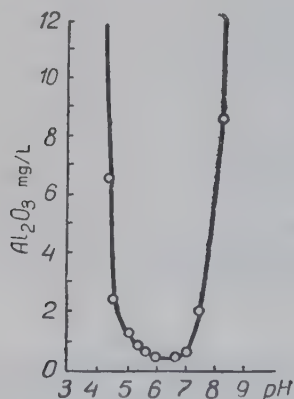


FIGURE 13. Solubility of alumina in water at different pH values (according to Magistad; quoted from I. I. Ginzburg and I. A. Rukavishnikova, 1951)

Celadonite veins form in slightly weathered basalt by joint coagulation of  $\text{Fe}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{SiO}_2$  from colloidal solutions saturated with alkali. When the concentration of iron and alkali is small, chlorite and mountain leather occur. When the migrational ability of the iron is low (when the medium is slightly alkaline), and when the tendency of the alkalis to be adsorbed by argillaceous minerals is high, it becomes clear why the celadonite is always contained in the casings, directly in contact with the basalt providing the iron and alkali in composite mountain leather-celadonite veins. Veins of hypogene calcite are formed on account of the calcium released from femic minerals, glass and partially leached calcite from the plagioclase.

In the zone of greatly decomposed rock there is an almost complete breakdown of all the primary minerals, which leads to regrouping of the material released in the process. In this zone most alumina and silica is released (mainly through decomposition of the plagioclase) during the same sedimentation process in which the iron-enriched argillaceous minerals of the montmorillonite group are formed.

In the second zone, the medium approaches neutral, and in certain sections even becomes slightly acidic, a condition necessary for the formation of halloysite (pH = 6.5 to 7.0).

On account of the fact that the sphere of activity in the zone of greatly decomposed rocks is occupied by basic quantities of inert components<sup>6</sup> -  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  - mobility is much lower compared with mineral constituents of the previous zones, especially in view of the lower pH value of the solutions. In the second zone the argillaceous minerals do not usually form veins, but stay in the same spot in the form of small concentrations within the rock. Here hypogene minerals, i. e., mountain leather, celadonite and chlorite, forming at the beginning of the weathering of the basalt also enter the sphere of decomposition; by losing alkali, calcium and some magnesium cations, they also turn into iron montmorillonite. Here the chlorite passes through the intermediate stage of jefferisite.

In the ochreous loam zone the chemical affinity of the medium remains in essence exactly as it was in the second zone. The process of the decomposition of the primary

<sup>6</sup> The most inert components in the given case are  $\text{P}_2\text{O}_5$  and  $\text{TiO}_2$ , recorded in apatite and ilmenite, stable with respect to weathering. The relative amount of  $\text{TiO}_2$  in weathered basalt is usually even increased (see table 1).

silicates with the formation of argillaceous minerals, montmorillonite-vidyllite-nontronite and halloysite is finally completed.

On account of the increased permeability of the loose masses of the upper zone to surface solutions and air, oxidation is very intense at this point. This leads to decomposition of the argillaceous minerals in the constituent oxides - the so-called ochering of the iron-bearing montmorillonites (Ginzburg and Rukavishnikova, 1951), which is most typical of the ochrous loam zone.

Thus, a definite zonation, which depends mainly on the water solution reaction, can be observed in the distribution of striated silicates making up the weathered crust.

In the case of iron hydroxides, precipitation from the oxide solutions occurs at  $\text{pH} = 5.5$ . Hence in the basalt weathered crust, where this degree of acidity is practically impossible,<sup>7</sup> the transfer of iron is greatly restricted, and the iron hydroxides remain chiefly in the same spot where they were formed. The formation occurred directly after the release of iron from the primary silicates. The iron hydroxides are spread out more or less equally through the zones of the weathered basalt.

The precipitation of manganese from the solutions in which it is contained in the form of a well-dissolved bicarbonate, is conditioned by the oxygen and carbonic acid conditions, and also by the reaction in solution. Manganese is easily oxidized to the tri- and quadrivalent forms, which sharply reduces its mobility; hence the precipitation of manganese hydroxide begins in the lowest part of the weathered crust, but only in small quantities, mainly in the form of a mechanical addition to the hypergene calcite. Most of the manganese, released from the hypergene minerals, is precipitated in the second zone.<sup>8</sup>

The solutions circulating in the ochrous loam zone are released chiefly from the dissolved manganese, hence the amount of manganese hydroxide in this zone is considerably less than in the second zone. More typical of the manganese in solutions, in the form of a well-dissolved bicarbonate, and therefore

possessing high mobility, is a deposit in fractures and in large complex veins, rather than the formation of finely-dispersed segregations in the host rock (which is characteristic of iron hydroxide).

The precipitation of calcite in the weathered crust depends on the quantity of free carbonic acid. At the bottom of the crust, the free carbonic acid is contained in solutions to a minimum extent, since it is precisely here that there is intensive leaching from the silicates of the alkaline and alkaline-earth cations, which immediately combine with the carbonic acid to form bicarbonates (the content and phase composition of the latter determine to a considerable extent the pH value of the solutions in the crust of basic and ultrabasic rock) and form the so-called "alkaline reserve" of the ground water. The solutions in the lower part of the weathered crust (third zone) are therefore more saturated with different bicarbonates, and this, as the alkaline reserve becomes greater (as the solutions move farther into the fresh rock), leads to precipitation of calcite, for which a pH value of about 8.0 to 8.5 (not less than 7.5) is required, and can be found here in the bottom part of the crust. Thus, calcite genetically associated with weathered basalt occurs predominantly in slightly weathered rocks of the third zone, and, like mountain leather and celadonite, often forms veins in basalt which is practically untouched by weathering (fourth zone). But on account of the redeposition of carbonate material from the chalk roof layer, the calcite veins are just as common in the top of the weathered crust as at the bottom.

Silica is released from the silicates throughout their complex stage-by-stage process of formation during weathering. In minerals with an  $\text{SiO}_2$  composition (chalcedony, quartzite, quartz and opal) no selective assignment to one part of the vertical section of the weathered crust has been noted. But although silica has a great deal of mobility in the slightly weathered basalt, where the solutions cause a pronounced alkaline reaction, and mainly form veins, often of great thickness, in the ochrous loam zone in a medium close to neutral, the silica released during ochering of the nontronite remains in the same place in the form of fine neogenic chalcedony and opal dispersed throughout the argillaceous material.

Thus, a zonation in the distribution of hypergene minerals, determined by the conditions of their formation and stability, was observed in the weathered crust of Volynya basalt. This is shown diagrammatically in Table 4.

Examination of the complex of hypergene minerals and their genesis leads us to the conclusion that the weathered crust of the basalt in West Volynya represents a typical

<sup>7</sup>A local reduction in the pH value could only occur at certain points, when hydrothermal pyrite and marcasite reached the sphere of alteration; this is of little importance compared with the whole weathered crust.

<sup>8</sup>A special case is the wad concentrations which are formed when manganese-bearing hydrothermal calcite is replaced; they may also be found in various types of slightly weathered basalts.



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TABLE 4. Distribution of Hypergene Minerals In Weathered Crust of West Volynya Basalts\*

| Number | Zones**   | pH                    | Process determining nature of zone  | Chief minerals  | Subsidiary minerals   |
|--------|---|-----------------------|---|---|---|
| 1      | Ocherous loam   | 7.0-7.8<br>(upto 6.5) | Ocherization of nontronite, decomposition of minerals into constituent oxides as a result of intensive oxidation.   | Montmorillonite-nontro-<br>nite. Halloysite. Iron<br>hydroxides. Minerals<br>with SiO <sub>2</sub> (quartz,<br>chalcedony, quartzine,<br>opal). | Manganese<br>hydroxide.<br>Calcite.   |
| 2      | Greatly decom-<br>posed rocks<br>which have<br>lost original<br>structure.  | 7.0-8.0<br>(upto 6.5) | Intensive breakdown of<br>plagioclase. Oxidation<br>and hydration of minerals<br>continues. Mobile com-<br>ponents almost completely<br>removed. Nascent min-<br>erals mainly composed of<br>SiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> and Fe <sub>2</sub> O <sub>3</sub> ,<br>and form predominantly<br>residual concentrations.   | Montmorillonite-nontro-<br>nite. Halloysite. SiO <sub>2</sub><br>minerals. Iron hydrox-<br>ide and manganese<br>hydroxide. Calcite.             | Celadonite.<br>Mountain<br>leather.<br>Jefferisite.                           |
| 3      | Altered rocks<br>with partially<br>retained<br>initial basalt<br>structure. | 7.8-9.0               | Intensive leaching of<br>bases, oxidation and hy-<br>dration of primary min-<br>erals. Breakdown of femic<br>minerals and glass pre-<br>dominates; alkalies and<br>calcium are only partly<br>removed from plagioclase.<br>Great mobility of all ox-<br>ides (including SiO <sub>2</sub> and<br>Al <sub>2</sub> O <sub>3</sub> ). Hypergene min-<br>erals form veins and fine<br>neogenic grains. | Celadonite, mountain<br>leather. Calcite.<br>Minerals with SiO <sub>2</sub> .   | Iron and<br>manganese<br>hydroxide.<br>Montmorillo-<br>nite-nont-<br>tronite. |
| 4      | Basalt slightly<br>affected by<br>weathering<br>or not<br>altered at all.   | 7.8-9.0               | No changes in rock for<br>practical purposes. In<br>some cases leaching,<br>hydration and oxidation<br>of silicates begin. In<br>fractures penetrating third<br>third zone there appear<br>veins of hypergene<br>minerals.  | Celadonite. Mountain<br>leather. Calcite.<br>Minerals with SiO <sub>2</sub> .   | Iron and<br>manganese<br>hydroxide.<br>Chlorite.                              |

\* The table does not include hypergene cuprite, malachite and azurite which have formed through oxidation of the hydrothermal copper minerals; nor does it include local changes in the pH value near concretions of hydrothermal minerals which have entered the weathering zone.

\*\* The sequence in which the zones are described corresponds to their position in a vertical section of the weathered crust.

case of a weathered crust formed over a long period in rocks of basic composition in a fairly warm and humid climate.

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# A BRIEF HISTORICAL REVIEW AND THE PRESENT STATUS ON THE GEOBOTANICAL METHOD IN GEOLOGY<sup>1</sup>

by

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translated by Gaida M. Hughes<sup>2</sup>

## ABSTRACT

A review of the literature shows that the relation of plants to geologic and hydrologic conditions has been recognized for several centuries. The geobotanical method is well adapted to ground-water and ore searches, and relies heavily on interpretation of aerial photographs. Its use in general geologic mapping is increasing. --M. Russell.

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Among the auxiliary methods currently employed in geologic (and especially in aerial geologic) studies, the so-called geobotanical method has become rather common during the past several years. It is based upon the utilization of geobotanical data (i. e., science about plant cover and about the associations of plants which compose this cover) as indirect indicators in geologic mapping, in the interpretation of aerial geologic photographs, in the prospecting for mineral resources, in hydrogeologic and geochemical studies and so forth.

Utilization of the plant cover as an indicator of geologic and hydrogeologic conditions was known in ancient times. It was especially well known that the distribution of plants depends upon the moisture content of the soil, and a list of plants which indicate the proximity of water was compiled by Vitruvius.

More definite suggestions pertaining to plants as indicators of mineral deposits are found in the writings of M. V. Lomonosov in 1763. A. N. Radishchev in his book "A Description of My Estate" writes about plants which indicate the presence of different types of rocks, "Birch indicates poor clay, but pine, juniper and Sem-pervivum indicate dry sandy loam" (1841, p. 189).

Systematic discussion of plants as indicators of geologic conditions for the first time was presented in the work of A. Karpinsky (1841) "Can Growing Plants Serve as Indicators of Rocks and Formations on Which They are Found and Do Their Stations Deserve the Particular Attention of the Geognocist".

This article, having been published in a journal which was not concerned with geologic problems, evidently was not noticed by researchers and was forgotten. Although the factual information in Karpinsky's article is rather poor, it nevertheless deserves attention not only as the first work on this subject matter, but also because it contains interesting theoretical suppositions. More interesting is the fact that Karpinsky was somewhat skeptical of the value of individual plants as indicators of geologic conditions, and believed that a more accurate picture of the soil conditions may be obtained from observations of the flora, i. e., of all species found in a given area.

Independently of Karpinsky, P. A. Ososkov, a geologist, also used the geobotanical method. He found a practical application of geobotanical observations in his geologic surveying of the Ussuri Region (1896) and the Volga region (1909, 1911, 1912). On the basis of the results obtained in his studies, P. A. Ososkov concludes that the geobotanical method is fully applicable, especially in areas covered by forests. Geobotanical observations in the Ussuri Region were of a decisive value for the successful completion of geologic surveying.

At the same time, but independently of Ososkov, the geologist N. K. Vysotsky (1904) used the geobotanical method in his investigations conducted in the Northern Urals. He gave a valuable description of the adaptability of different types of forests to the olivine rocks, to gabbro-diorites, and to diallage periodites in the northern part of the former Perm Province.

Thus, A. M. Karpinsky, P. A. Ososkov and N. K. Vysotsky pioneered the application of the geobotanical method in geology.

During the later years only a few researchers devoted their attention to this subject, and a review of their work has been presented earlier (Viktorov, 1955).

A somewhat independent course in the development of the geobotanical method was revealed by publications concerned with the application

<sup>1</sup>Translated from *Kratkii ocherk istorii razvitiya i sovremennogo sostoyaniya geobotanicheskogo metoda i geologii*; in symposium volume *Geobotanicheskiye metody pri geologicheskikh issledovaniyakh*, [Geobotanical Methods for Geologic Investigations] pp. 5-10, Gosgeoltekhnizdat, Moscow, 1955. Reviewed for technical content by Herbert E. Hawkes, Jr.

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of the geobotanical indicators in prospecting for ground water. In the articles of a number of hydrogeologists one finds references to the usefulness of geobotanical observations in hydrogeologic research. V. A. Prinklonsky (1935) wrote an article on this subject and showed that geobotanical observations reduce considerably the cost of prospecting for ground water, make possible a more rational distribution of drill holes and facilitate the forecasting of the presence of water.

Prospecting for ore deposits by means of studying the content of these deposits and the accompanying compounds in plant ashes began with the investigations of Aleksandrov (Fersman, 1939). This method, which is more biogeochemical than geobotanical, is being successfully used by S. M. Tklich (1938) and D. P. Milyuga (1947).

The establishment of the Aerogeologic Service in the Ministry of Geology and Conservation of Natural Resources was an important step in the development of the geobotanical method for geology. Beginning with the year 1945, aerogeologic organizations in the staff of their geologic expeditions include a detail of geobotanists. The geobotanical method is becoming an inseparable part of aerogeologic research.

Reference should be made to a number of currently published works on studies by this author and by N. G. Nesvetaylova, D. D. Vyshivkin, and others which are in more detail discussed in this symposium.

Considering in brief the essence of the geobotanical method in geology, it must be pointed out that this method is based on a supposition that a close relationship and reciprocity exists for all elements in nature. This supposition was rather extensively developed by V. V. Dokuchaev. His ideas, which were further developed by his students, V. I. Vernadsky, F. I. Levinson-Lessing and later by A. Ye. Fersman and B. B. Polinov, were the theoretical foundations upon which it became possible to establish and develop the geobotanical method in geology.

Of especially great significance is the work of B. B. Polinov (1952) concerning the so-called geochemical landscapes. B. B. Polinov's geochemical landscapes are elementary combinations of rocks including the soil which covers them, and the plant associations which grow there. In such combinations the plant cover may be considered as an indicator of the geochemical processes which occur in a given landscape, and the character and stages of these processes may be determined by geobotanical observations.

In substance, the geobotanical method in geology consists of finding some differences and characteristics in the plant cover, which would be closely and clearly tied in with char-

acteristics of the geologic structure and the hydrogeologic conditions of that area, and the utilization of these geobotanical signs for geologic mapping and in prospecting for useful mineral deposits.

Not to discuss in detail all geobotanical characteristics, it should only be noted that the most varied characteristics of the structure of plants may be used for purposes of geologic mapping and prospecting. Widely used are such easily noticeable signs as the dominance of different plant forms on different rocks (for example, trees and bushes on some rocks, but herbaceous plants on others). Differences of this kind are fully reflected on aerial photographs and can easily be noted not only by a specialist, geobotanist, but by an investigator who has had experience in identification.

A more specialized research is required for the analysis of those cases where on two different rocks develop plant associations which are similar in their general appearance but different in specie composition. As an example we may consider the steppe plant association which grows in dry semidesert areas of the U. S. S. R. (Western Kazakhstan, Lower Volga banks and other regions), on sands of various ages and of different lithologic composition.

Despite the apparent physiological similarity of these steppe regions, a geobotanical study and especially as complete as possible study of the floristic composition of vegetation, allows to determine the adaptability of different associations to formations of different age and different lithology.

The adaptability of individual species of plants also requires a special geobotanical study. Since it is well known that some plant species are reliable indicators of certain compounds, geobotanical observations of this kind are especially important in prospecting for minerals.

A very important group of geobotanical characteristics used in geologic investigations consists of characteristics pertaining the distribution of certain individual plants under different geologic and hydrogeologic conditions.

Geobotanists of the All-Union Aerogeologic Trust showed that the density of individuals of the same species greatly varies depending upon hydrogeologic conditions such as the mineral content, the depth of occurrence of ground water and the chemistry of soil producing bedrocks. The study and utilization of density and the preparation of special distribution graphs is a very important component part of geobotanical research in serial geologic studies.

Among the geobotanical observations made for aerial geology, quite important is the study of all possible types of deformities of plants and



deviations from the normal appearance, found in a number of plants as a result of the presence of certain elements in the soil. These geobotanical characteristics are especially widely used in prospecting for oil, since it has been established that an increased bitumen content in the soil produces anomalies of form.

Lately attention has been devoted to the study of plant vitality (i. e., under given geologic conditions their acquisition of an oppressed, normal, or luxuriant appearance), since it is known that normal vitality in plants is disturbed in regions which have an increased tectonic activity.

Characteristics which are currently used in geobotanical research for geologic purposes are as follows: 1) general appearance of the plant cover and the dominance of a certain level of vitality, 2) species compositions of the plant cover, 3) a narrow geologic-adaptability range of individual species, 4) the distribution pattern for individual plants, 5) the presence and distribution of deformities and deviations from the normal form caused by soil conditions and 6) changes in plant vitality.

The field for the application of geobotanical observations in geology and especially in aerial geologic studies is constantly increasing. The geobotanical method is currently used in the most diverse branches of geology and hydrogeology. By geobotanical information it is possible to detect and to determine the spread of a number of useful mineral deposits. Thus, the All-Union Aerogeologic Trust began the utilization of geobotanical information in prospecting for polymetals and has already met with some success in this endeavor. Utilization of the geobotanical method in prospecting for sulfur is in a developmental stage. Utilization of geobotanical indicators in prospecting for oil has become common.

Geobotanical signs are extremely widely used in the search for shallow ground water in arid regions.

The application of the geobotanical method in geology is not limited to prospecting for useful mineral deposits. Geobotanical characteristics have proven themselves to be extremely valuable in the geologic mapping of poorly exposed regions where the camouflage of the ground by plant cover makes difficult the separation of different formations. Geologic mapping by the All-Union Aerogeologic Trust was conducted mostly in the plains regions of Kazakhstan and Central Asia. But the work of P. A. Ososkov, mentioned earlier, leads us to believe that this method may be successfully used in wooded areas as well.

A special field of application of the geobotanical method is the preparation of soil

salinity maps on the basis of geobotanical information.

The All Union Aerogeologic Trust successfully utilizes geobotanical information in the preparation of lithologic maps of porous ancient alluvium deposits where difficulty was presented by great interstratification, of sand, sandy loam, argillaceous soil, and clay strata in a small area.

The number of problems which may be solved by the application of the geobotanical method, at present time may not by any means be considered as complete. Further development of the geobotanical method must first of all be directed toward a wider utilization of geobotanical indicators in prospecting for mineral resources.

It should also be emphasized that the utilization of geobotanical method in geology is extremely new. Currently it is being developed by a small number of researchers almost exclusively in the All-Union Aerogeologic Trust. It is hoped that a greater number of scientists working in this field and a further perfection of method and theory will produce considerable improvement of the results which can be obtained by use of the geobotanical method.

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# UTILIZATION OF GEBOTANICAL INDICATORS IN AEROGEOLOGIC MAPPING IN WESTERN KAZAKHSTAN<sup>1</sup>

by

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• translated by Gaida M. Hughes<sup>2</sup> •

## ABSTRACT

Geobotanical methods were useful in geologic mapping of Cretaceous to Triassic rocks of the Temirsk and Aktyubinska regions of western Kazakhstan. Eleven vegetation assemblages helped distinguish lithology, salinity conditions and geologic age. --M. Russell.

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In geologic mapping of Western Kazakhstan certain difficulties were encountered in regions characterized by small exposures of lithologically similar rocks. The most serious difficulty was in determining the exact contact between different types of deposits, because the information obtained for individual points (drill holes, mines) always is somewhat indefinite.

Geobotanical research is very valuable in geologic mapping. A geobotanist studies the plants in the area, determines the adaptability of certain species of plants to different rocks, and prepares a so-called "geo-indicating" geobotanical map.

This map is fundamentally an ordinary geobotanical map (i. e., a map of vegetation) showing the adaptability of each species considered to different lithology and, in most instances, also to the deposits of different ages. A "geo-indicating" geobotanical map may be utilized by a geologist, and the boundaries indicated by the geobotanist may serve as auxiliary material in geologic mapping. Often it is necessary only to verify the geobotanical boundaries by a small number of drill holes and to compare geobotanical information with geologic data before the boundaries from the "geo-indicating" map may be transferred to a geologic map.

The work of the All-Union Aerogeologic Trust in preparing a "geo-indicating" map may be divided into two basic parts:

1) Study of plant communities and their role as indicators in the territory investigated;

2) The process of mapping.

The study of the role of plants as geologic indicators ordinarily is divided into three stages.

The first stage consists of the study of available literature on vegetation, geology and geomorphology. Sometimes on the basis of general geographic information it is possible to estimate the geologic adaptability of plants. The research of N. N. Dsens-Litovsky, M. M. Ilyina and P. U. Rozhevits may be mentioned as an example where a geographic sketch contains a series of important data on geologic adaptability of plants.

Even more important is the second stage of research — field study to determine the role of plants as geologic indicators. For this purpose ordinarily a detailed study and description is made of the so-called "standard sections". A "standard section" is any small area of which a thorough geologic study has been made. Most frequently such "standard sections" are located adjacent to drill holes and mining pits where it is possible for the geologist to provide the geobotanist with very accurate geologic data. Complete geobotanical description is obtained for these sections; including a description of vegetation, designation of control areas, study of the abundance of plants, their blooming seasons, vitality, specie composition, etc., and the charting of horizontal and vertical projections. Then geomorphological conditions of the area are described and, most important, a thorough description is made of the mining pit or drill hole (logging of the core is especially desirable).

When sufficient factual material has been collected on the "standard sections" (not fewer than five "standard sections" for the same species), follows the third stage of the research, — generalization of the information obtained in studying "standard sections", i. e., the showing of what value one or another type of community may be as an indicator. These generalizations may be presented in a so-called "geo-indicating scheme, i. e., on tables which show the significance of plant communities as indicators.

<sup>1</sup> Translated from *Ispolzovaniye geobotanicheskikh priznakov pri aerogeologicheskoy kartirovani v. Zap. Kazakhstane*; in symposium volume *Geobotanicheskiye metody pri geologicheskikh issledovaniyakh* [Geobotanical Methods for Geologic Investigations] pp. 11-18, Gosgeolizdat, 1955. Reviewed for technical content by Herbert E. Hawkes, Jr.

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The data obtained by geobotanists of the All-

Union Aerogeologic Trust may be mentioned as an example of a study where plant covering was used as an indicator for a number of formations of different ages and of different lithology. This research was conducted in the Temirsk and Aktyubinska regions in 1950. In these areas a continuous geo-indicating botanical mapping was carried out for the purpose of aiding geologists-surveyors in their attempts to determine the contacts between a variety of rocks which are difficult to establish by ordinary geologic methods.

The greatest part of this territory was composed of Cretaceous rocks. Widely distributed were the deposits of Aptian and lower Albian, represented by black and gray argillaceous clays. Equally abundant were the series of the upper Albian and Cenomanian stage, composed primarily of sands. Santonian deposits were represented by sands containing phosphorites, and Campanian deposits were present in a series of greenish and grayish-green argillaceous clays. Permian-Triassic deposits — red gypsiferous clays — had a very limited distribution. Occasionally areas composed of ferriferous sands and sandstone of the continental deposits of the Oligocene were encountered.

From the above brief description it is apparent that the territory investigated contained lithologically rather uniform deposits; mostly different gypsiferous clays and various types of sands. The relief of this region was poorly developed and natural exposures rare. Therefore, in order to determine the geologic contacts, in wide water parting areas [widely separated streams?] it was necessary either to carry out extensive drilling operations or to map by outcrops — procedures which [in this area] do not always produce reliable results.

Mapping was considerably facilitated by the use of geobotanical indicators, because there was a great contrast of plant covering on all of the above-mentioned deposits. Following will be a brief description of the plant covering on deposits of different ages.

On Permian-Triassic red clays grow unique plant communities which exhibit stunted growth, similar to that of typical desert plants, and in general appearance greatly differ from the desert-steppe plants growing in the area. In areas where rocks were more exposed grew stunted communities of desert underbrush composed of *Anabasis salsa* and *Atriplex cana*. These plants were from one-third to one-fifth the size common for these species. Besides the two above-mentioned plants, a unique halophytic plant *Camanthus gamocarpus* was common, which did not grow on any other rocks in the Aktyubinska Ural region, but is ordinarily found in the flora of southern deserts (Karakum, Southern Ustyurt). Where rocks were

covered with lumpy solonchak of variable thickness, grew a community of peculiar wormwood, the so-called "mai-kara" (*Artemisia maicara*), which ordinarily is found only considerably further south (Bet-Pak-Dala), and *Artemisia Les-singiana*. These plants make up poor flora and the areas where they grow look like true miniature fragments of a desert. The abnormally small forms and the distinctive golden coloring are so noticeable that these areas may be unmistakably recognized from far away. The extremely high salinity of these rocks (over 1 percent sodium sulfate content) must be responsible for desert plants' growing in this area and for their stunted appearance. The gray and black clays of the Albian and Aptian deposits are also very saline (salt content is higher than 3 percent, of which 1.9 percent come from gypsum). On these rocks typically develop societies with the following three dominant species of plants: dense clumps of succulent dark green or brownish-violet *Anabasis salsa*, little bushes of brownish-yellow *Artemisia pauciflora*, and a gray, dwarfed, pillow-shaped specimen of *Camphorosma monspeliacum*. Combination of these species gives such a unique, complex appearance to the areas of dark gypsiferous clays that even from an airplane they may easily be recognized by the spottiness and variegation of vegetation. For example, in 1950, in the valley of river Shegerli-Kumda, a sizeable area of Aptian deposits was discovered solely on the basis of geobotanical signs, criteria, and only later were these findings confirmed by drilling.

Geologists encountered great difficulty in determining the exact contacts of upper Albian and Cenomanian sands because of the lithological uniformity and poor fauna of these beds. However, the different origin of these deposits (marine origin of Cenomanian sands and continental origin of the upper Albian) left a definite imprint on their chemistry. Cenomanian sands had a high salt content (chloride content not less than 0.025 percent and not less than 0.1 percent sulfate content), but the sands of the upper Albian had almost no salts (0.005 percent chlorides, not more than 0.025 percent sulfates). Accordingly, on the upper Albian sands was found a luxurious, colorful, multiherbaceous steppe composed of *Stipa capillata*, *S. loannis*, *Agropyrum sibiricum*, and a great number of colorful grasses (species of the family *Jurinea* *Scorzonera* *Silene*, and others). On Cenomanian sands the steppe has a different appearance: it is almost colorless, plant covering is composed mostly of small grayish underbrush of *Artemisia incana*, and grasses, of which *Festuca sulcata* is the dominant species. There is a great contrast between these bleak, monotonous areas and colorful steppes on upper Albian series.

In the Albian deposits of Aktyubinska Ural region, a study was made of a horizon of white sands and sandstone. Frequently this horizon



was covered with diluvium, or was greatly altered by an admixture of soil in the upper layers of earth. The high carbonate content of this horizon was responsible for the development of unique plant societies with Echinops ritro and especially tall, luxuriant Kochia prostrata plants, which permitted easy location of this horizon. Because of the high phosphorite content of Santonian deposits, which increases the fertility of soils forming on these deposits, they may be recognized by the extremely luxuriant growth of vegetation. Typical is a brushwood steppe with Artemisia incana, Stipa sareptana, and variegated, luxuriant herbaceous plants, which to a certain extent are similar to a steppe on upper Albian deposits. However, the abundance of plants of the leguminous family, especially, Caragana frutex, serves as an identifying sign of a steppe on Santonian deposits. Caragana is spottily distributed in the form of a rather heavy underbrush around which grow variegated grasses, thus forming a Caragana-herbaceous association.

The areas of Caragana-herbaceous association are noticeable due to the bright green color even in midsummer, dense, tall grassy cover (general cover up to 90-100 percent), and the variety in specie composition. Adaptability of Caragana to Santonian rocks may be explained by the fact that representatives of the leguminous family, as has been mentioned by A. P. Shennikov, are more capable of increasing the solubility of phosphates by the secretion of their roots than are other plants, especially grasses. Grasses requiring an especially great amount of phosphorus at the time of their bushing out and fruiting, find favorable conditions growing in association with Caragana because they have an opportunity to utilize freely the necessary phosphorus.

The presence of various steppe grasses, as well as the appearance of Spiraea hypericifolia plants near Caragana, may partly be due to an increased water content caused by the fact that the Caragana and grasses retain snow and prevent moisture loss.

On greenish-gray Campanian substage clays, very rich in gypsum content (0.95 percent  $\text{CaSO}_4$ ), grow societies of Artemisia pauciflora, Bassia sedoides, Salsola brachiata, and societies of which the dominant plant is a desert grass — Elymus lanuginosus. This combination of societies forms an intricate, colorful mosaic composed of small, brownish bushes of Artemisia pauciflora, bluish-gray saltworts, and lemon-yellow patches of Elymus lanuginosus, the latter drying up very early in summer. The total picture is of such a unique color that areas occupied by Campanian series can be unmistakably recognized. In studying territories occupied by Campanian deposits on which Artemisia pauciflora-Salsola Elymus lanuginosus complexes are developed, we very often

find areas with Caragana and Stipa sareptana, characteristic for phosphorite-containing Santonian sands. Closer studies of these areas have revealed that at a depth from 1 to 3 m under a thin cover of Campanian clays are located deposits of the Santonian substage. In these instances one series appears to be "shining through"; another series. This phenomenon evidently must be explained by the fact that the root systems of plants (especially those of bushes) are spreading into the series of phosphorite-bearing sands. Therefore, gypsum-loving species (Artemisia incana, etc.) are gradually replaced by species which grow on rocks rich in phosphorus content.

In other instances a reversed relationship is observed. On a luxuriant, colorful steppe, typical for the Santonian series, suddenly appear scattered patches of Artemisia incana-saltwort societies. Boring reveals that areas with Artemisia incana-saltwort vegetation are composed of a unique residue of Campanian clays which had eroded almost to the level of Santonian deposits. The vegetation typical for Campanian deposits enables a very accurate mapping of these areas.

In Primugodzhaz, a region somewhat further to the east, we utilized geobotanical indicators in our study to determine the various formations of the Paleogene period. A. L. Yanshin (1953) in this region separated the Tasarianian, Saxaulian and Cheganian formations. Most common were the Tasarianian formations, composed of greenish-gray gypsiferous clays. A society of Anabasis depressa which grows in tall and dense clumps is the characteristic vegetation on Tasarianian clays. These plants grow up to 30 or 40 cm in height, and form an unusual landscape where the brownish-red clumps of Anabasis depressa blend with the background of the dark, poor soil developed on Tasarianian formations. Clumpy Anabasis depressa plants occupy great areas, are easily recognized by their color in aerial observation, and serve as very accurate indicators of the location of clays of the Tasarianian formation. Other species of plants here are almost absent. Salsola brachiata and Lepidium perfoliatum plants appear only infrequently.

It should be noted, that on gypsiferous clays of lower Albian and Campanian age one may also infrequently observe cover composed of a single species of Anabasis, but this is either another species (Anabasis salsa), or it may be the same species but not growing in clumps. The clumpy form of Anabasis depressa grows exclusively on Tasarianian formation.

In the sandy deposits of Akyutbinska Ural region, widely distributed sands and sandstone of continental deposits of the Turgaisky series of Oligocene, and their outcrops are characterized by an accumulation of coarse detritus rich in

fragmental ferruginous sandstone. These deposits contain only an insignificant quantity of salts. Soboleva (1951) mentions that barite is present in the continental series of Oligocene. Detritus habitats on sand and ferruginous sandstone deposits develop typical desert plants: Artrophytum pulvinatum, Nanophyton erinaceum, and even Haloxylon aphyllum. It may be accepted as true that the reason for the penetration and growing of desert plants in these habitats may be attributed to a number of complex conditions of which the temperature conditions play an important part; namely, the detritus allows for an easy warming of the substrata.

the point of view of the ecologist, the phytophrapher, or the geomorphologist, nevertheless, by its appearance and rare occurrence in some areas, leaves an imprint that reflects a specific ecological nature of these areas, and indicates a special course of their geologic development" (Popov, 1940, p. 6).

On Oligocene deposits desert plants penetrate very far to the north. One of the furthest locations of detritus semidesert on continental series of Oligocene is found in the upper Shileshi-Sai and in the basin of Ilel river. Another area is located in the basin of river Uil (sai Zharli).

A fragment of the geo-indicating scheme for Aktyubinska-Ural area

| Vegetation   | Geo-Indicating Significance                       |   |  |
|--|---|---|--|
|  | Lithologic Characteristics                        | Salinity  | Age  |
| Colonies of dwarf <u>Anabasis salsa</u> , <u>Atriplex cana</u>   | Gypsiferous red clays                             | Very strongly sulfate   | -  |
| Societies of <u>Artemisia maicara</u> and <u>A. Lessingiana</u>  | Gypsiferous red clays                             | Very strongly sulfate   | -  |
| Complexes with <u>Artemisia pauciflora</u> and <u>Elymus lanuginosus</u> dominant  | Gypsiferous green clays                           | Strongly sulfate  | Campanian  |
| <u>Artemisia incana</u> - <u>Stipa capillata</u> steppe with <u>Artemisia pauciflora</u> and <u>Elymus lanuginosus</u> spots | Thin layers of gypsiferous green clays over sands | Medium sulfate  | Campanian with shallow underlayer of Santonian sands |
| <u>Artemisia pauciflora</u> - <u>Anabasis salsa</u> - <u>Camphorosma monspeliacum</u> complexes                              | Gray and black gypsiferous clays                  | Sulfate   | Lower Albian and Aptian                              |
| Clumps of <u>Anabasis salsa</u>  | Greenish gypsiferous clays                        | Strongly sulfate  | Tasarianian series of Paleogene                      |
| Brushwood steppe with <u>Caragana fruitex</u>  | Phosphorite-bearing sands                         | Insignificant   | Santonian  |
| Herbaceous colorful steppe   | Phosphorite-bearing sands                         | Practically none  | Upper Albian   |
| Herbaceous- <u>Artemisia</u> , colorless steppe  | Sands   | Slightly chloride   | Cenomanian   |
| Colony of <u>Artrophytum pulvinatum</u> , <u>Anabasis salsa</u> and <u>Nanophyton erinaceum</u>                              | Ferruginous, detritus sands and sandstones        | Slight ( $Cl^-$ and $SO_4^{2-}$ traces); barite evidently present | Turgai series of continental Oligocene               |
| <u>Artemisia</u> -herbaceous association with considerable presence of <u>Echinops ritra</u>                                 | White sandstone and detritus sands                | Slight  | Middle Albian  |

The presence of fragments of desert vegetation, despite the small areas occupied by them, gives the continental series of Oligocene a unique external appearance. M. G. Popov also had noted this unusual appearance of areas where Artrophytum pulvinatum was found. He writes, "The presence of Artrophytum in a desert, although it may not have any significance from

In generalizing the above discussion, we will present a brief geo-indicating outline on the adaptability of plants to bedrocks. It is based first on the listing of plant societies which serve as indicators of various types of clays, and then on listing societies which serve as indicators of sands and sandstones.



The above material permits the conclusion to be drawn that in poorly exposed flat areas geobotanical observations may be helpful in geologic mapping and may facilitate the reading of aerial photographs.

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# AN EXPERIMENT ON THE APPLICATIONS OF GEOBOTANICAL GUIDES IN DISTINGUISHING BETWEEN LITHOLOGICALLY SIMILAR STRATA OF DIFFERENT ORIGIN<sup>1</sup>

by

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## ABSTRACT

This article will present the techniques and the various steps followed in the utilization of geobotanical indicators for geologic mapping of areas east of and adjacent to the Mugodzarskiye mountains. It was found that despite the apparent homogeneity of the plant cover on lithologically similar rocks, a geobotanical analysis reveals a number of fundamental differences. Even when the floristic composition of associations is the same, other differences are seen in quantitative ratios of species, in the occurrence of some species in the plant cover, and finally, in the development cycle of an association as a whole, or of its individual species. In many instances also considerable floristic differences are observed in the plant cover found on lithologically similar rocks. Differences in plant cover on lithologically similar formations result from the physical chemical properties of rocks, which in turn result from the origin of rocks, the conditions of their formation, and the depths of their occurrence. In utilizing geobotanical data for lithological mapping, of great importance is the character of plants growing at the contacts of formations which emerge at the surface. The following regularly occurring characteristics were noted. a) Hydrophytes develop at the contacts of rocks of different lithologic composition when impermeable rocks underlie permeable and moderately permeable rocks (sandstone, marly sandstone). b) At the contact of rocks of a different lithologic composition, when water-impermeable rocks (clays) overlie water-permeable rocks (sand, sandstone, marly sandstone) vegetation quickly dries up because the overlying rocks are dry as a result of being separated from the ground water. c) A transitional zone of plants is observed at the contacts of lithologically similar rocks and makes possible the determination of the boundaries of these rocks. The boundaries may be very sharp if the lithologically similar rocks have a different type and amount of salinity. --M. Russell.

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Geobotanical investigations are of very great importance in geologic mapping in those instances where deposits of different origin are lithologically similar and are difficult to distinguish by external signs. For example, such phenomenon has been observed in Western Kazakhstan in the mapping of the Cretaceous and Tertiary deposits. Here we encountered similar and difficult to distinguish sand formations in Albian and Cenomanian deposits, as well as in Santonian and Oligocene formations. Similar gypsiferous clays are also found in Albian and Turonian deposits, etc.

In this case, the plant cover was a very important auxiliary indicator in the mapping of the above-named formations. The experiment concerning the application of geobotanical signs in geologic mapping of Western Kazakhstan has already been briefly described (Viktorov, 1951;

Vostokova, 1953); but these descriptions were mostly for the western part of the area. This article will present the technique and the various steps followed in the utilization of geobotanical indicators for mapping of lithologically similar strata of eastern areas adjacent to Mugodzarskiye mountains.

In order to determine the nature of the relationship which exists between plant cover and the bed rocks of the area studied, we will examine the changes in plant cover by profile which stretches along the southeastern wing of the Chushkakulsky anticline, and cuts across clays of the Turonian, sands of the Cenomanian and sands and clays of Albian stages.

Plant cover on the Turonian clays is composed of an *Anabasis salsa* and *Anabasis depressa* associations including some *Artemisia pauciflora* and *Atriplex cana*. Structure of the association is simple -- consists of one grade. The 5 to 8 cm grade is formed by *Anabasis salsa* and *Anabasis depressa*, since *Artemisia pauciflora* and *Atriplex cana* are found only as individuals and are not significant in the structure of plant cover; 25 to 30 percent of the soil is covered.

On the fine Cenomanian stage sands which come in contact with Turonian clays, was the association consisting of *Stripa sareptana*, *Agropyrum desertorum*, *Artemisia incana*, and some *Kochia prostrata*. The first grade, 50

<sup>1</sup>Translated from Opyt primeneniya geobotanicheskikh priznakov pri raschlenenii litologicheskikh skhodnykh tolshch razlichnogo proiskhozhdeniya: in symposium volume Geobotanicheskiye metody pri geologicheskikh issledovaniyakh [Geobotanical Methods for Geologic Investigations], pp. 19-43, Gosgeolizdat, Moscow, 1955. Reviewed for technical content by Herbert E. Hawkes, Jr.

<sup>2</sup>U.S. Geological Survey.



to 60 cm high, is formed by Stipa sareptana, Agropyrum desertorum and Kochia prostrata. Second grade, 30 to 35 cm high, is formed by Artemisia incana. Soil coverage is 50 to 60 percent.

On Albian sands, which come into contact with Cenomanian stage sands is an association consisting of Artemisia incana, an admixture of Kochia prostrata, Eurotia ceratoides and Stipa sareptana. Very thin plant cover of the first grade, actually appearing like a fragment of the first grade, is 50 to 60 cm high, and is formed by Stipa sareptana and Eurotia ceratoides. Second grade, 25 to 35 cm high, is formed by Artemisia incana and Kochia prostrata. Soil coverage is 40 to 50 percent.

Finally, on Albian clays we find an association of Anabasis salsa and spots of Artemisia terra-albae.

A comparison of the above described plant associations shows an especially sharp difference between the cover over clay and the cover over sand which corresponds to the differences in their properties. Thus, the community coefficient (i. e., the percentage ratio of species which are common to both types of rock, to the total number of species found on these rocks) between the associations found on Turonian clays and those found on Cenomanian sands is 0 percent. Community coefficient between plant associations on Albian sands and Albian clays is 12.5 percent.

In a geobotanical analysis of the associations, we learned about one factor which was important for our study. Namely, that the plant cover growing on rocks of a similar lithologic composition but of different origin, is also not the same. For example, the community coefficient between plant association found on Albian sands, and associations found on Cenomanian sands is only 50 percent. Thus, only one-half of the species observed are common for the sands of both ages. The other half consisted of species which were typical either for Albian or Cenomanian sands.

In an analysis of associations found on Albian and on Cenomanian sands it was found that plant cover on the Albian sands has considerably fewer grasses and has relatively more heteroherbaceous plants. The major component of the plant association on Albian sands is Artemisia incana, but Agropyrum desertorum and Stipa sareptana plays only a small part in the composition of the plant cover. On Cenomanian sands Stipa sareptana and Agropyrum desertorum are the co-dominant species in a Stipa sareptana-Agropyrum desertorum-Artemisia incana association. Besides, the plant cover on Cenomanian sands is considerably better developed (especially Kochia prostrata, which here grows up to 60 cm tall, while on Albian

sands it is only 30 to 35 cm tall), and has a longer vegetation period. There are also differences in the development cycle. At the time, when on Albian sands the plant cover is beginning to dry up, on Cenomanian sands it is still fresh. When the character of the plant cover on argillaceous Santonian sands is compared with the above-described sands, the great difference between them becomes obvious even at the most superficial examination.

While on Albian sands develops an Artemisia incana association with an admixture of Stipa sareptana, Kochia prostrata, and Eurotia ceratoides, on the Santonian sands grows a complex of Artemisia terrae-albae association with the presence of Stipa sareptana, Eurotia ceratoides, and Anabasis aphylla, and the association of Anabasis salsa (sometimes with presence of Artemisia pauciflora). Community coefficient between associations developed on Albian and those on Santonian sands altogether is only 30 percent. The complex nature of the plant cover on Santonian sands results from the rather high degree of salinity, indicated by the presence of Anabasis salsa and Artemisia pauciflora. The percentage of occurrence for the last two increases with the salinity of sands.

Finally, plant cover on the Oligocene sands differs even more from the plants found on the above-discussed sands. In the areas investigated the coarse, consertal, iron-containing Oligocene sands contain the highest salinity because they contain shallow interstratifications of saline clay. Plant cover found on Oligocene sands is a four-component complex consisting of 1) an association of Artemisia terrae-albae, 2) an association of Stipa sareptana-Artemisia terrae-albae, 3) Anabasis salsa association and 4) Salsola branchiata association. The community coefficient between the association on Albian sands and the association found on Oligocene sands altogether is only 25 percent, but for the association on Santonian sands and the association on Oligocene sands is 50 percent. The unique character of vegetation on Oligocene sands has already been noted by E. A. Vostokova (1953) who showed that the iron-containing Oligocene sands serve as a pathway for the northward penetration of desert plants (particularly, Haloxylon aphyllum).

From the above discussion it follows that, although at a first glance the plant cover found on sands of different origin may appear to be homogeneous, a geobotanical analysis of vegetation discloses a number of substantial differences. Even when the floristic composition of associations is more or less similar, these differences are revealed by the quantity ratios of different species, by differences in the occurrence of one or another kind of species in the plant cover, and finally, by differences in the development cycle of the whole association or of its individual species. In many instances,

significant floristic differences are also observed for the plant cover over sands of a different origin.

It should be noted that the characteristics of the plant cover on Albian and Cenomanian sands which we observed in the region of the Chushka-kul anticline are somewhat different from characteristics of sands of the same period, observed by E. A. Vostokova (1953) in regions further to the west. According to her observations, for Albian sands characteristic is the predominance of colorful heteroherbaceous grasses, but for Cenomanian sands—predominance of Gramineae and colorless heteroherbaceous components. As already mentioned, we also noted a predominance of Gramineae on Cenomanian sands. However, the plant covering on Albian sands was not colorful, even though the heteroherbaceous composition continued to be a characteristic for our region as well. Those changes in the appearance of the plant cover on Albian sands evidently result from a change in the lithology of Albian deposits in the area of the Chushka-kul anticline. A. L. Yanshin (1953) points out that Albian sands in this area are enriched by Mugodzarsky rock, and continues to explain that the Albian strata here contain red interstratifications which are common only for Chushka-kul anticline and are not present in the Emba basin.

At any rate, we may emphasize that the method used for the separation of sand strata of the Cretaceous and Tertiary deposits by plant covering, which for the first time was utilized by the geobotanists of All-Union Aerogeologic Trust in the Uila basin, is entirely suitable (with certain corrections) for the eastern regions as well.

The differences in the plant cover on lithologically similar deposits will become even more evident when a detailed analysis is made of the structural characteristics of the plant cover, i. e., when the differences in the distribution of the dominant species within an association are determined, and a study is made of the changes which occur in the size of one and the same species growing on different rocks.

These characteristics of plant associations were noted first of all because the distribution of individuals of one species and their size greatly influence the photographic representation of an area. Discovery of the relationship which exists between the above noted characteristics, and the geologic conditions, made possible the utilization of geobotanical characteristics in aerial geologic studies. More detailed geobotanical investigations were made for the purpose of determining this relationship, and they consisted of measuring the distances between those individuals which were the chief component of the associations studied.

The distribution of individuals of a species within an association until this time has had little discussion in literature, despite the fact that the first work on the subject appeared in print already in the beginning of this century. In the year 1918, G. R. Eytingen published an article on the influence of density of trees on their height, and somewhat later, in 1927, A. I. Leskov wrote about the variation of distances between trees in a fir forest. Both of these authors tried to determine the course of changes in the distance between trees as related to their age. As a result of their investigations, they came to the conclusion that the distance between individuals of the same tree species at the time when they have attained considerable age has been established by a reciprocal action of individual plants, and therefore, the distance is biologically specified.

G. I. Dokhman lately has studied the distribution of individuals of the same species within an association but the results of her work, unfortunately, have not yet been published. She developed a very effective method for showing the distribution of a species within an association by means of a distribution graph. The graph indicating distribution of a species is constructed in the following manner: classes of distances between individuals of the same species are given on the abscissa, and ordinate shows the number of measurements for each class of distances, expressed in percentages of the total number of measurements taken. The curve which connects the number of measurements taken in each class of distances very clearly represents the distribution of individuals of a species in an area. Distribution graphs currently are successfully used by many researchers in this field of study.

The above authors who studied the nature of distribution of species within an association did not consider the influence of ecological conditions, i. e., the influence of the habitat. Inasmuch as a relationship between the individuals of one species is established within the framework of certain ecologic conditions of the habitat, it is obvious that a definite connection will exist between the conditions of the habitat and the distribution of individuals of a species within an association.

Since the distance between plants is a result of complex interrelationships, which occur under definite ecologic conditions, between individuals of the same species, it follows that in different habitats the distribution graph for the same species also must be different.

Distribution graphs for the dominant species within an association were used by this author in analyzing lithologically similar strata of different origins. Analogical investigations were carried out by L. F. Voronkova on ancient alluvial Amu-Darya plains (see Voronkova's article



in this symposium).

In an arid climate where this study was made, a given morphological sign of an association becomes especially important. It is known that in deserts and in semidesert areas the structure and composition of an association depends greatly on conditions for existence, and is limited by these conditions. It is therefore obvious that under certain conditions of the habitat only a definite fixed number of plants is able to exist.

In semidesert areas the basic factors determining the conditions for plant existence are moisture and salinity of the soil, which in turn, depend on the lithological composition of rocks. Consequently, rocks of a given lithological composition establish definite ecological conditions which determine not only the specie composition in an association, but also its structure. Obviously under given ecological conditions, the distribution of plants (especially that of edifiers) in an association will be more or less stable.

*Artemisia incana* is the most important edifier of the plant associations growing on sand deposits in the regions which we investigated. In order to study the differences in the distribution of *Artemisia* on sands of different ori-

gins, we measured the distance between individuals in different areas (25 to 50 measurements were taken in each area). On the basis of this information distribution graphs were made for each section. Then, by averaging all graphs we obtained the mean distribution graph for a given rock.

We constructed distribution graphs for *Artemisia incana* on the following sand deposits — Albian, Oligocene and Santonian. An examination of these graphs reveals considerable differences (figure 1).

The greatest density of *Artemisia* is observed on Oligocene sands (74 percent of all measurements are in the class 0-20 cm), and generally, the distance between plants is not greater than 60 cm. The cause of such high density of *Artemisia*, evidently, must lie in the fact that coarse-grained Oligocene sands have undergone more leaching. This interpretation is confirmed by the fact that in those instances where these very same sands are located over shallowly underlying strata of clay rich in salt, the distribution graph sharply changes: the maximum content moves to the 20-40 cm interval, and a considerable number of individuals (5 percent) are located in the distance range of 60-100 cm.

On consertal Albian sands (with clay inter-

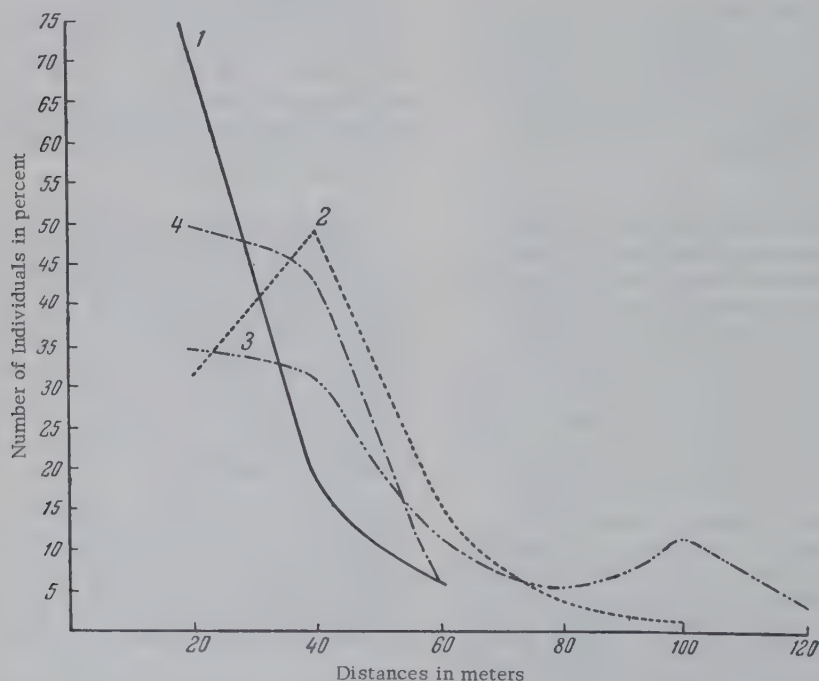


FIGURE 1. Mean distribution graphs for *Artemisia incana*

1) - On coarse-grained Oligocene sands; 2) - on coarse-grained Oligocene sands overlying shallow clay beds; 3) - on argillaceous Santonian sands; 4) - on consertal Albian sands.

stratification) the density of *Artemisia* is also lower than on Oligocene sands, although the maximum distance between individual plants still is not greater than 60 cm; the maximum in the range from 0 to 20 cm, however, here is expressed less sharply than on the graph for Oligocene sands.

On argillaceous in some areas saline Santonian sands, *Artemisia incana* is even less dense. Maximum by location and value here is almost the same as maximum for Albian sands. However, a characteristic difference of the *Artemisia incana* distribution graph on Santonian sands is the elongated right side, which on the graph forms a second maximum.

The above brief analysis of the graphs leads to conclude that for each of the strata considered, there is a specific, and only for this stratum characteristic, type of distribution of the most common plant — *Artemisia incana*.

In view of the fact that the density of *Artemisia incana* is rather well expressed on aerial photographs by its coloring (the greater the density, the darker the color hue), it becomes possible to utilize the information obtained in the identification of sands of different origin.

In areas with little exposure, considerable practical difficulties in geologic field investigations are presented not only by sands but also clays, which have various types of solonetz areas formed on them, and when the solonetztes are covered by much alike *Anabasis salsa* associations.

Measurements were made of the distances between *Anabasis salsa* plants in order to determine differences in the structure of plant cover found on clays of various origins. In the area which we studied, *Anabasis salsa* associa-

tions were most common on Turonian and Paleogene clays and on Maastrichtian marls. These measurements showed that the distribution graphs for *Anabasis salsa* on heavy soils of different origin is also different (figure 2).

On Turonian clays the greatest part of *Anabasis salsa* plants (66 percent) are situated at a distance of 3 to 40 cm from each other. A small number of individuals (12 percent) — are from 40 to 60 cm from each other. Then the number gradually decreases and only 1.7 percent *Anabasis salsa* plants are situated at a distance of 120 cm from each other.

On Tasaranian clays of the Paleogene stope the distribution of *Anabasis salsa* is entirely different. Here the greatest part is distributed at a distance of 60 cm from each other. With increase in the distance, the number of individuals rapidly decreases, and only 5 percent of *Anabasis salsa* plants are situated at a distance from 80 to 100 cm, although a second small maximum is found in the range from 120 to 140 cm.

A comparison of graphs reveals, that *Anabasis salsa* on Tasaranian clays forms a thinner plant cover which evidently is due to the higher salinity of these clays.

Finally, the mean distribution graph of *Anabasis salsa* on Maastrichtian marls greatly differs from the graphs we considered earlier. The first maximum appears at distances from 60 to 80 cm, the second small maximum, at a distance from 100 to 120 cm, and finally, even smaller third maximum is at a distance from 260 to 300 cm. *Anabasis salsa* distribution graph indicates that the plant cover is thinnest on Maastrichtian marls, and in some instances individuals may be situated even at a distance from 300 to 320 cm from each other.

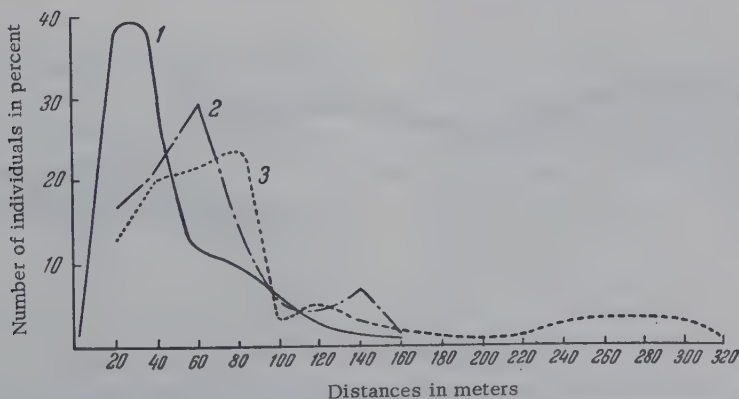


FIGURE 2. Mean distribution of *Anabasis salsa* on heavy soils of different ages.

1) — On Turonian stope clays; 2) — on Tasaransky stage clays; 3) — on Maastrichtian stage marls.



Thus, it becomes possible to use the distribution graphs for the identification of rocks also on heavy soils in areas with small exposure.

The study of the nature of distribution was partly supplemented by observations of those varieties which produce the same species but grow on different rocks. There are numerous examples of such varieties (Viktorov, 1952). We studied the changes in the size of Anabasis salsa growing on clays and marls.

For this purpose many measurements were taken of the diameters of Anabasis salsa plants growing on different rocks. As a result, it was learned that the average diameters of Anabasis salsa plants on heavy soils were different when soils were of different origin. The average diameter of Anabasis salsa on Tasarianian clays was 29 cm, on Turonian formations — 36 cm, and on Maastrichtian marls — 45 cm.

It is necessary to note that all of the differences in the plant covering on similar strata have resulted from differences in the physical-chemical properties of these strata, which were set by the origin of the rocks, the conditions of their formation, and also the depth of their location. The geologic age of rocks (in the direct sense of the word) in this case is not significant. The term 'age' of rocks we use in the sense of a geologic epoch, which is characterized by certain conditions under which the rocks were formed and situated, and consequently, in the sense of related physical characteristics of deposits of a given period.

It must be emphasized, however, that since it was possible that in geologic epochs different conditions for the formation of rocks could exist, one should not discard entirely the notion of using the plant cover in isolated instances for mapping deposits of different ages.

In utilizing geobotanical data for lithological mapping, it is very important to study the plant cover on the contacts between various formations which emerge at the surface.

We made this kind of a study in the region adjacent to the Chushka-kul anticline. The study of the plant cover was done along the contacts between lithologically different rocks.

The study revealed that the character of vegetation on contact areas depends mostly upon the lithological composition of rocks, since the lithological composition of rocks, since the lithological composition determines the moisture properties (moisture capacity, moisture permeability and capillary capacity).

A description of the plant cover found on the contacts of lithologically different rocks appears below:

1. On contacts of Turonian stage clays and Cenomanian stage sands, sand is located under clay. When layers are close, water supply in soil becomes lower, soil does not receive water by capillaries from the ground water, the overlying rocks dry out and plants quickly dry up. The contact between the above-named rocks is expressed very clearly (fig. 3). An association of Anabasis salsa with some admixture of Artemisia pauciflora and Atriplex cana was found on Turonian clay. Stipa sareptana-Agropyrum desertorum-Artemisia incana association was characteristic for Cenomanian sands. On contacts between Turonian clay and Cenomanian sands plant cover was very sparse and had an oppressed appearance. Anabasis salsa plants were low-growing and dry, while on slopes and on top of a mound composed of Turonian clays, this plant has a normal appearance and height.

2. In the region investigated very frequently

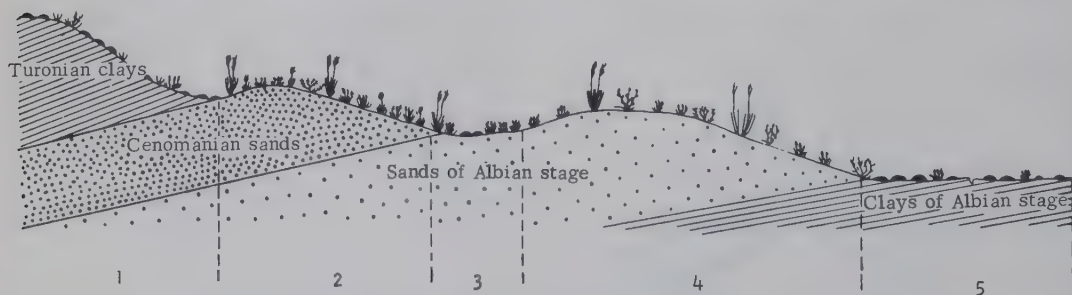


FIGURE 3. Schematic profile of vegetation over sand and clay contacts.

1) - Anabasis salsa associated with admixture of Artemisia pauciflora and Atriplex cana; 2) - Stipa sareptana, Artemisia incana, Agropyrum desertorum associated with Eurotia ceratoides and Kochia prostrata; 3) - Artemisia incana association with the presence of Anabasis aphylla, Eurotia ceratoides, Stipa capillata and patches of Anabasis salsa; 4) - Artemisia incana associated with patches of Eurotia ceratoides, Kochia prostrata and Stipa capillata; 5) - Anabasis salsa associated with patches of Artemisia incana.

there was contact between Saksaulskiye sands and Akchatskiye clays.

Along the borders of these rocks clay is situated under the sand, and as a result of this, accumulation of water occurs in the overlying water-permeable rocks. This is revealed by the presence of springs and hydrophytic vegetation along the contact lines.

The springs and hydrophytic plants are found on the contacts between Saksaulskiye sands and the Akchatskiye clay substrata of Paleogene in the northern part of the territory which we investigated (fig. 4). Artemisia arenaria-Festuca

sandstone.

3. Where the dark gray sandstone marls of Tasaranian stage come in contact with clays of the Campanian stage, water also accumulates in the overlying rocks which have a low permeability, but evidently, due to the low permeability of the marls, the water-bearing horizon is not as thick as at the contact of sands and clays. Therefore, at the contacts of these rocks a mesophytic vegetation (Agropyrum oristatum, Bromus tectorum, Stipa capillata, etc.) develops, while on the clays of the Campanian stage grows a very sparse cover composed of an Artemisia incana-Anabasis salsa

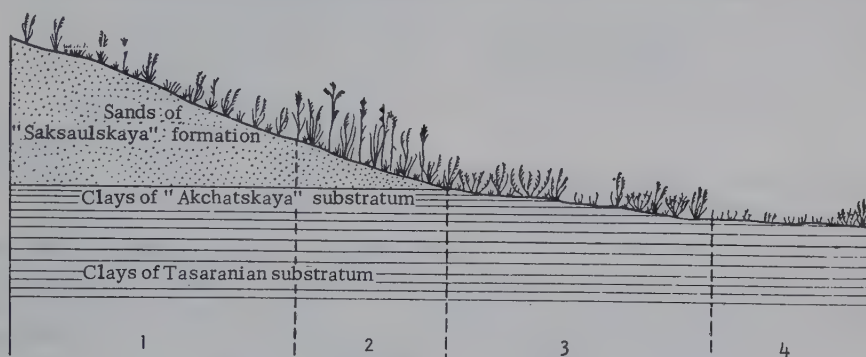


FIGURE 4. Schematic profile of vegetation

1) - Stipa capillata-Festuca sulcata association with heteroherbaceous plants; 2) - Stipa capillata-Festuca sulcata-heteroherbaceous association with hydrophytic vegetation; 3) - a complex of Stipa capillata-Festuca sulcata association (with Spiraea hypericifolia) with Artemisia pauciflora and Artemisia incana associations; 4) a complex of associations including Artemisia pauciflora, Artemisia incana and Stipa capillata-Festuca sulcata (with Spiraea hypericifolia).

sulcata association and heteroherbaceous plants grow on the Saksaulskiye sands. A complex of Spiraea hypericifolia, Stipa capillata, and Artemisia incana grows on the Akchatskiye clay substratum.

An association of Stipa sareptana-Festuca sulcata and heteroherbaceous plants with the hydrophytes - Calamagrostis epigeios, Phragmites communis, Sanguisorbia officinalis, Bromus inermis, etc., found on the contacts of Saksaulskiye and Akchatskiye clays.

The strip of hydrophytic vegetation on contacts of the same rocks at the foot of the Chagrayskoye plateau "chinki" was traced with interruptions but springs here were almost nonexistent. On the bluffs of the Chagrayskoye plateau a strip of hydrophytic vegetation high on the slope of the contact line between the Oligocene sands and Saksaulskiye clays was observed. Both bonds of the hydrophytic vegetation are clearly visible on aerial photographs. However, there were no hydrophytes on the contacts of cemented sandstones and clays (fig. 5), as a result of the water-impermeable nature of

association, but on the Tasaranian marls—a Festuca sulcata-Artemisia incana association with spots of Artemisia pauciflora.

Thus, a hydrophytic vegetation develops on the contact of rocks of a different lithologic composition, when water-impermeable rocks underlie permeable or moderately permeable rocks, and produces either single species associations or is part of the plant cover found on the overlying rocks.

When the impermeable rocks are located at a great depth, hydrophytic associations are not present, but the vegetation at the contact is considerably better developed, has a longer vegetation period and is more noticeable on the general background of plants.

These are the unique characteristics of the plant cover at the contact of lithologically different rocks, in the regions investigated.

In addition, we also attempted to study the characteristics of contacts between lithologically similar rocks, since the determination of



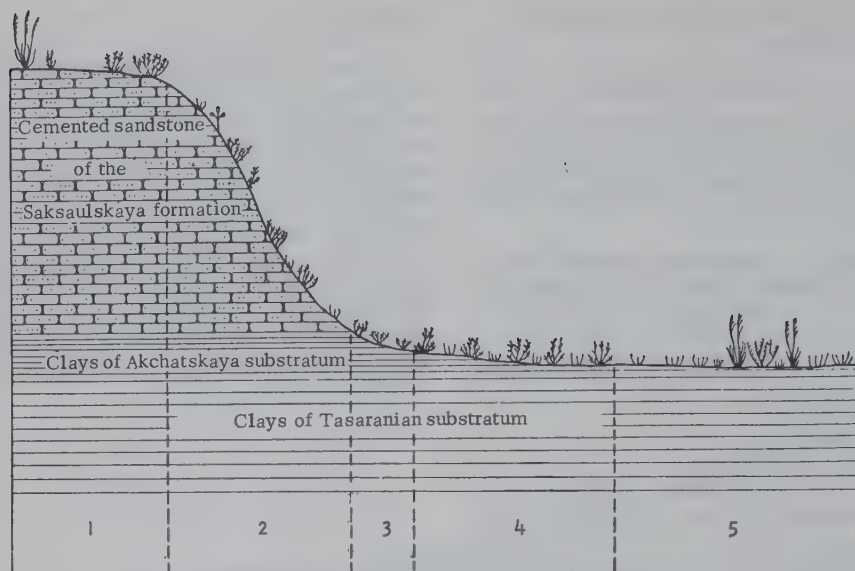


FIGURE 5. Scheme representing a profile of the vegetation

1) - Sparse cover of *Stipa capillata*, "Tyrsa",\* *Festuca sulcata*, *Artemisia incana*, *Spiraea hypericifolia*, "kurchavka",\* and "Efedra",\*; 2) - a sparse cover consisting of "sinegolovnik",\* *Spiraea hypericifolia*, (in depressions), *Artemisia*, *Camphorosma monspeliacum*; 3) - sparse cover consisting of *Artemisia pauciflora*, *Artemisia incana* and "kurchavka";\* 4) - *Artemisia pauciflora*-*Atriplex cana* association; 5) - a complex of associations of *Artemisia incana*, *Artemisia pauciflora*, *Stipa capillata*-*Festuca sulcata* (with *Spiraea hypericifolia*).

\*Local names.

their boundaries presents a great problem in lithological mapping. We studied the contacts between the Akchatskiye "marly" clays and the bluffs of the Tasaranian steppe, which were very common in the northern part of the area studied.

On the marlaceous clays we found a complex of *Spiraea hypericifolia*-*Stipa sareptana*-*Festuca sulcata* association with *Artemisia incana* and *Festuca sulcata*-*Artemisia incana* associations. On the bluffs of the Tasaranian, which had a higher salinity, grew a complex of a *Spiraea hypericifolia*-*Stipa capillata*-*Festuca sulcata* association with *Artemisia incana*, *Anabasis salsa*, and *Nanophyton erinaceum* associations.

At the contacts of the above rocks we found a zone approximately two meters wide on which we noted a transition from one type of a complex to the other by means of a displacement of the basic components. A band of transitional vegetation is produced by which it is possible to determine the boundaries of rocks that otherwise are difficult to separate. A similar type of contact was also observed in the area of the Chushka-kul anticline between the Cenomanian stage sands and the Albian sands. *Stipa sareptana*-*Agropyrum desertorum*-*Artemisia incana* association developed on the Cenomanian sands. The plant cover on the Albian sands is composed of an association of *Artemisia incana*

with an admixture of *Kochia prostrata*, *Stipa sareptana* and *Eurotia ceratoides*. The narrow strip of transitional vegetation, found on the contact of these rocks, allowed us to determine the boundaries between them.

As a result of this study it was found that the nature of the vegetation at the contact of various geologic rocks indicated the degree of similarity which exists between the contact rocks.

In addition, the information about the character of the plant cover at the contact of rocks may also be utilized in the study of tectonic disturbance lines, faults, overthrusts, etc.

Figure 6 schematically represents a fault which was traced by vegetation on the southeastern limb of the Chushka-kul anticline. The line of the fault is clearly identified by a sharp boundary between the *Anabasis salsa* association (on Turonian clays), and the *Artemisia incana* association with some presence of *Kochia prostrata* and *Stipa sareptana* found on the Albian sands.

By plants it was also possible to trace the line of the Mugodzarsky overthrust. Areas with springs and hydrophytic vegetation here were found along the entire line of the overthrust. Halophytes grow in those areas where saline ground water emerges at the surface.

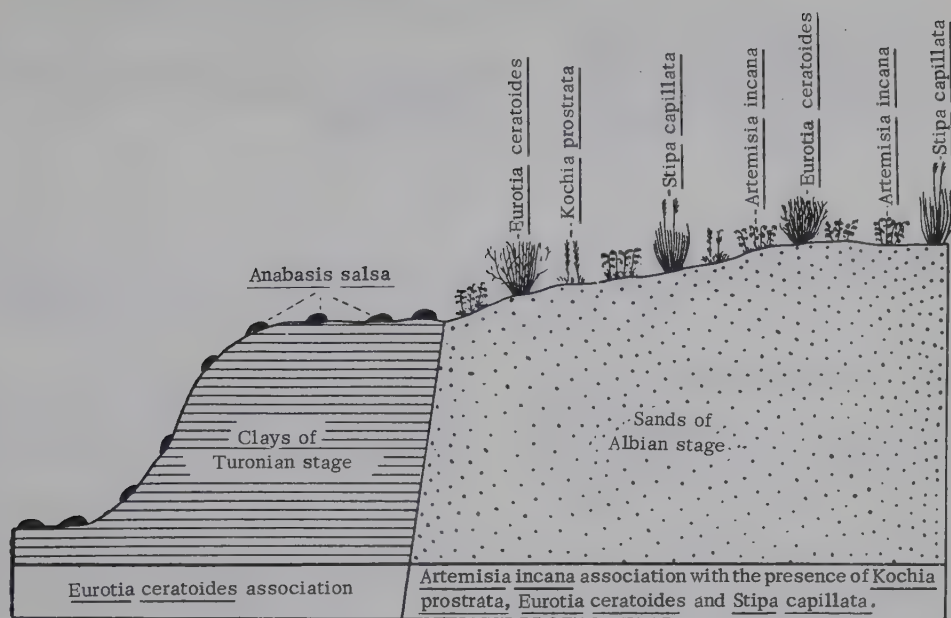


FIGURE 6. Scheme of the profile of vegetation across the line of fault

The following conclusions may be made on the basis of the relationship which was found to exist between plant associations and the lithological composition of soil-forming rocks.

1. Despite the apparent homogeneity of the plant cover on lithologically similar rocks, a geobotanical analysis of plants reveals a number of fundamental differences. Even when the floristic composition of associations is the same, these differences are expressed by differences in the occurrence of some species in the plant cover, and finally, by the differences in the development cycle of an association as a whole, or of its individual species. In many instances also considerable floristic differences are observed in the plant cover found on lithologically similar rocks.

2. Differences in plant cover on lithologically similar formations result from the physical-chemical properties of rocks, which in turn result from the origin of rocks, the conditions of their formation, and the depths of their occurrence.

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# UTILIZATION OF THE GEOBOTANICAL METHOD IN LITHOLOGIC MAPPING OF EARLY ALLUVIAL DEPOSITS<sup>1</sup>

by

L. F. Voronkova

translated by Gaida M. Hughes<sup>2</sup>

## ABSTRACT

Analysis of plant cover is a useful tool in detecting lithologic distinctions in alluvial deposits. Application of the method in mapping the Kunya-Darya plain in Turkmenia is described. The genus *Haloxylon* is a sensitive indicator of lithology. -- M. Russell.

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Increased cultivation of cotton and other crops on the alluvial plains along the Amu-Darya and Syr-Darya rivers of Central Asia requires a considerable expansion of irrigation systems.

Inasmuch as the classification of the ground is of great importance in the planning of hydro-technical construction projects, it is necessary to prepare geologic, and especially lithologic maps of recent and early alluvial deposits.

The greatest difficulty in such mapping is encountered from the extreme heterogeneity of the alluvial series.

A complex of deposits found in a drill hole in Turkmenia on the early Kunya-Darya alluvial plain may serve as an example of the lithologic variety of these series. In a thickness of 10 meters here we may separate 13 layers of the following lithological varieties:

- 1) sandy loam, pulverized, of bluish-gray color, thickness -- 0.26 m;
- 2) brown pulverized sand, thickness -- 0.07 m;
- 3) brown argillaceous soil, thickness -- 0.67 m;
- 4) light-green sandy loam, pulverized, thickness -- 0.5 m;
- 5) brown argillaceous soil, thickness -- 0.74 m;
- 6) light-brown, pulverized sand, thickness -- 0.36 m;
- 7) light-brown clay, thickness -- 0.15 m;
- 8) dark-gray, fine-grained sand, thickness -- 0.06 m;
- 9) light-brown clay, thickness -- 2.69 m;

- 10) dark-brown fine-grained sand, thickness -- 0.17 m;
- 11) light-brown clay, thickness -- 1.33 m;
- 12) micaceous, dark-gray, fine-grained sand, thickness -- 0.11 m;
- 13) light-brown clay, thickness -- 3.89 m.

In addition to the considerable variety of early alluvium in the vertical mechanical composition, extreme changes are also observed horizontally. Very many mechanical varieties of alluvium do not form a solid horizon, but are deposited as lenses or thin layers that quickly taper out. This may easily be seen by a comparison of the cores from several pairs of closely-spaced drill holes each. Thus in two drill holes, 20k and 19k, placed in the early alluvial Kunya-Darya plain in the area of Tarym-Kaya residual mountain, at a distance of 1.8 km from each other in a 10-meter thickness, the following relationship was found between the different mechanical varieties:

|                   | Drill hole 20k<br>percent | Drill hole 19k<br>percent |
|-------------------|---------------------------|---------------------------|
| Clays             | -                         | 60.6                      |
| Argillaceous soil | 18                        | .4                        |
| Sandy loam        | 15                        | 2.8                       |
| Sand              | 67                        | 32.6                      |

A similar picture is observed in a comparison of drill hole 30 and 33.

|                   | Drill hole 30<br>percent | Drill hole 33<br>percent |
|-------------------|--------------------------|--------------------------|
| Clays             | 7.4                      | 25.5                     |
| Argillaceous soil | 21                       | 23                       |
| Sandy loam        | -                        | 33.0                     |
| Sand              | 71.6                     | 12.5                     |

The above examples show that at points from 1 to 3 km apart, the early alluvial deposits of Kunya-Darya exhibit great differences in their structure.

In the presence of such a variety, the composition of a lithologic map by ordinary geologic survey methods would require a great deal of drilling. Even so, the boundary location of individual mechanical varieties would not be

<sup>1</sup>Translated from Opyt ispolzovaniya geobotanicheskogo metoda pri sostavlenii litologicheskoy karty drevneal-lyuvialnykh otlozhenii; in symposium volume Geo botanicheskiye metody pri geologicheskikh issledo-vaniyakh [Geobotanical Methods for Geologic Investi-gations], Gosgeoltekhizdat, Moscow, 1955, pp. 34-43. Reviewed for technical content by Herbert E. Hawkes, Jr.

<sup>2</sup>U.S. Geological Survey.



entirely exact, as the boundaries between drill holes would be estimated. The small exposure would also present difficulties in the mapping of this area. The lack of exposure is a result not only of a strong shifting of sands on the alluvial plains, but in long-irrigated areas is also due to transportation of soil by irrigation waters.

The above-mentioned characteristic of such deposits made it necessary to work out new mapping techniques. The use of the plant cover as an indicator of different lithologic varieties is an auxiliary method used in the preparation of maps of early alluvial deposits. Geologic as well as geobotanical data confirm the fact that plant cover reacts to any changes in the mechanical composition of rocks which form the soil.

Thus, N. P. Grave (1936), in studying the plant cover on alluvial deposits at the lower part of Amu-Darya river, discovered a distinct adaptability of various types of "tugai" vegetation to certain mechanical compositions of alluvium. He singled out societies that were typical for alluvial sandy loam (for example, the astragal "tugai", leguminous or buckbean "tugai"), for alluvial argillaceous soil (couch grass "tugai", comb-shaped "tugai"), etc. A. D. Fursayeva (1938) provided similar data for the area along the lower part of the Volga on the distribution of vegetation on alluvial deposits, depending upon the mechanical composition of the latter. Thus, it would appear that the relation between the plant cover and the mechanical composition of bed rocks forming the soil varies to the same extent as on older rocks.

These facts concerning a strong lithological adaptation of some plant societies and individual species, led us to believe that the vegetation on early alluvium deposits will also reflect the lithological conditions.

On this basis the geobotanists of the All-Union Aero-geologic Trust undertook a study of the applicability of the geobotanical method in lithological mapping of early alluvial strata in Kunya-Darya alluvial plain located between the Khorezm oasis and Sarykamyskaya depression. The present article summarizes the results of this study.

Extreme lithological variation is characteristic of this territory.

The high homogeneity of the plant cover composed of a solid mass of Haloxylon, with Haloxylon aphyllum as the dominant society, was another characteristic of the early alluvial plain.

The homogeneity of Haloxylon vegetation which stretched for many kilometers seemed to

preclude the possibility of determining the location of various soils by the plant cover, since the most widely used method for mapping lithologic varieties, based on the distribution of one or another kind of plant species, could not be utilized under these conditions.

However, more detailed observation and a study of aerial photographs showed that the mass of Haloxylon in the field was not the same. There were differences in the density, in dimensions of corollae, in height of individual plants, etc. These differences were apparent on aerial photographs.

The contrast between dense and sparse Haloxylon growth was visible on aerial photographs. The densely-growing Haloxylon plants are usually distinguished by their intensely dark, fused contours, but the sparse areas appear as a uniform light gray, the color determined by that of the soil. The light-gray background shows scattered specks which represent either individual plants or small clusters of Haloxylon plants.

Variation in the density and vitality of Haloxylon drew attention to the relationship that may exist between these characteristics and the soil conditions. It seemed likely that the density of Haloxylon is in some way dependent upon the mechanical composition of rocks below soil.

Earlier investigations of geobotanists of the All-Union Aero-geologic Trust (Viktorov, 1947, Vostokova, 1952) showed that, depending upon the moisture of the soil and upon the rocks which form the soil, the same species may be distributed differently, and that under given geologic and hydrogeologic conditions the nature of the distribution will be very specific.

Using this as a point of departure, we devoted most of our attention to the nature of the distribution of individual Haloxylon plants, and recorded the results on a distribution chart. However, it was later found that besides the distribution, certain other indexes could be utilized. They will be described later.

First of all we studied the vegetation on control areas, i. e., on areas where the vertical profile of early alluvial deposits was already known. These sections, as a rule, were situated close to drill holes, and occasionally at deep prospecting pits. On these sections, covering an area of approximately 2,000 m<sup>2</sup>, a detailed study with geobotanical descriptions was made, measuring of the distances between Haloxylon plants and the height of plants. Distances were measured from a given specimen to each adjacent plant. Then another central plant was selected and measuring repeated until a total of 100 measurements were taken (in few rare instances 50 measurements).

Simultaneously measurements were taken of the height of Haloxylon plants. Results were tabulated and charts prepared on the distribution of Haloxylon.

Besides distribution charts, diagrams were also prepared for all control sections showing the relationship of different mechanical varieties in a 10 m thickness of early alluvial deposits (information obtained by drilling).

Haloxylon distribution diagrams show several groups which greatly differ in their configuration and reveal a definite connection with the dominance of certain mechanical varieties in the early alluvial stratum:

1) graphs with a sharp decline and a clear single peak usually situated from 0 to 500 cm, are characteristic for strata where sands and sandy loam is dominant (fig. 1);

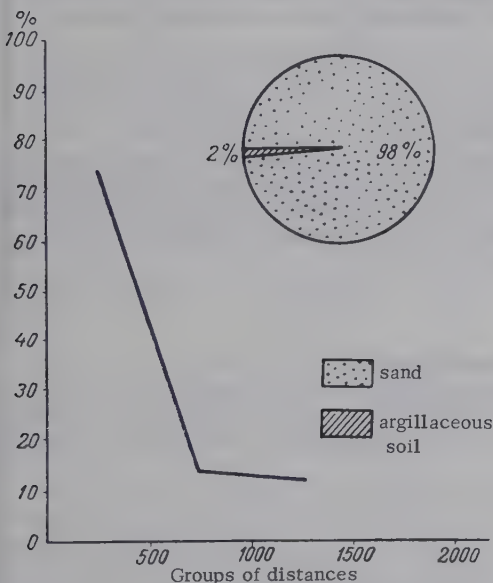


FIGURE 1. Distribution graph for Haloxylon in the Porsuymen pit region (from measurements on an aerial photograph)

2) extended graphs with several small peaks: the number of measurements in each group is usually small and the graph at times may become broken. This type of a graph is characteristic for strata where clay or very heavy argillaceous soil is dominant (fig. 2).

The differences in the distribution of Haloxylon on various soils most probably are based on the development of the root systems, but the development of the latter depends upon soil conditions.

The literature offers information on the changes in the root systems of the same species of plants when growing on different substrata (Weaver, 1919; Krasovskaya, 1925, and others). Petrov (1933) and Beydeman (1934) in their work note facts pertaining to the plasticity of root systems and its relationship to the substratum. The opinions of all these authors in essence express the idea that the same species when growing on different soils may produce wide variation configuration of the root systems. Also, when a water-bearing formation is accessible, the roots develop toward it. However, when a water-bearing horizon is absent, the plant in an effort to find moisture develops a strong and shallow root system, which encompasses as much soil as possible.

A similar phenomenon evidently is responsible for the distribution of Haloxylon on different soils. There is no doubt that sands often serve as condensers of moisture. Therefore, on predominantly sandy soils, Haloxylon develops chiefly vertical roots. Thus, the root systems are directed downward and plants are not prevented from growing close to each other. On heavy clay soils, where moisture conditions are considerably worse, the root system of Haloxylon branches out laterally. In these instances the root systems of Haloxylon hinder each other's growth which results in a thinning-out.

Besides the differences in distribution, there are also differences in external appearances due to a light or a heavy soil. Especially great

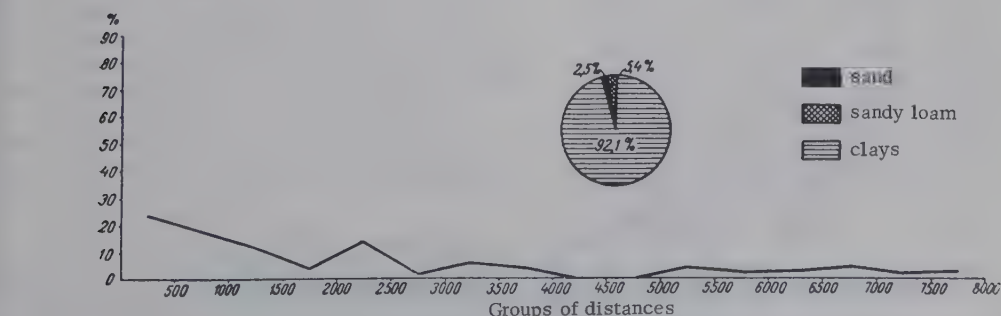


FIGURE 2. Distribution graph for Haloxylon in the Koi-Kyrlan mountain (from measurements on an aerial photograph)



variation is found in the height of the stalks. A mass measuring of the height of Haloxylon showed that those which grow on sections composed of clay or of argillaceous soil do not exceed 0.35 m to 0.5 m in height, while plants growing on sandy soil usually have a height of 1.5 m to 2 m. Besides, Haloxylon growing on sandy soil is thick, luxuriant and green, but plants on a heavy clay soil are low and dwarfed.

In order to apply this method of study to lithological mapping, it was necessary to learn the extent to which the differences found for Haloxylon growing on different lithological complexes may be determined by study of aerial photographs.

In particular, it was necessary to learn: a) whether it would be possible to prepare distribution graphs from measurements taken on aerial photographs, and b) the extent to which the graphs prepared from photographs would coincide with graphs prepared from ground measurements.

A certain basis for expecting a positive answer to this question was established by the work of S. V. Viktorov (1947) who writes that the distribution of some desert plants determined by measurements on the ground closely coincides with the measurements of contact prints.

Measurements on photographs were made by use of a Geneva ruler and optical equipment permitting the making of measurements of distances as small as 0.2 mm. A section with a more or less similar pattern was outlined on the photograph, and the taking of measurements limited to it. The distances between Haloxylon plants (appearing as dots on the print) were then measured from one end of the section to the other. Care was taken to prevent remeasuring. A total of 100 measurements was taken. The figures were treated like the data obtained on the ground.

A comparison of graphs from ground measurements and those from photographs showed a strong correlation.

By totaling the measurements obtained on sections of like mechanical composition, and processing the figures by the usual methods, we obtained the mean graphs. Mean graphs were prepared for both photographs and ground measurements.

A comparison of these mean graphs reveals that the differences between the three groups of graphs (for sand, clay and argillaceous soil) stand out very clearly (figures 3 and 4). The mean graphs for sand are practically the same. Those for argillaceous soil are also very similar. For clay a general correlation shows some differences in the position of the peaks on the

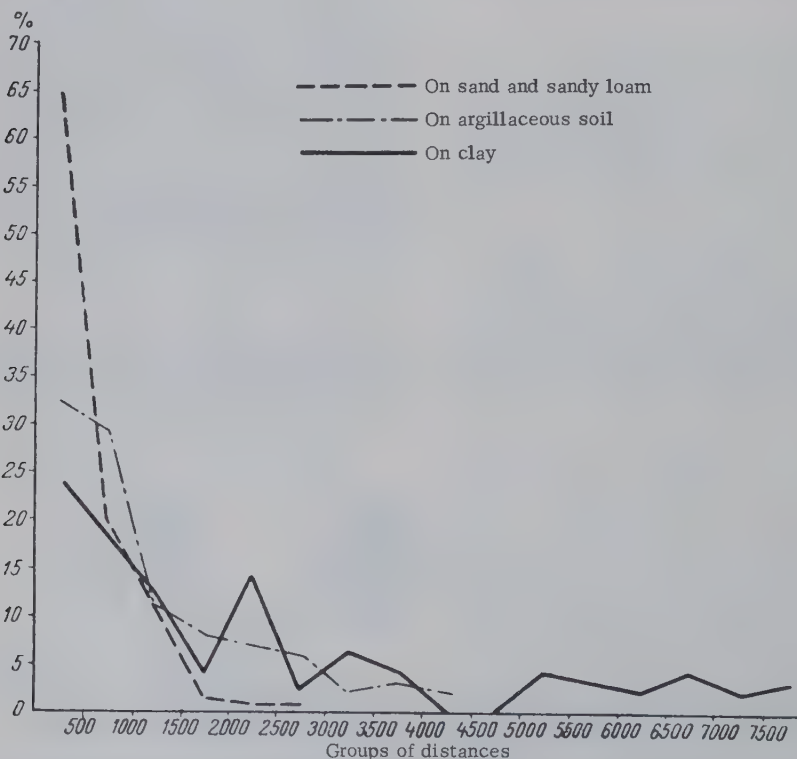


FIGURE 3. Mean distribution graph for Haloxylon (from measurements on an aerial photograph)

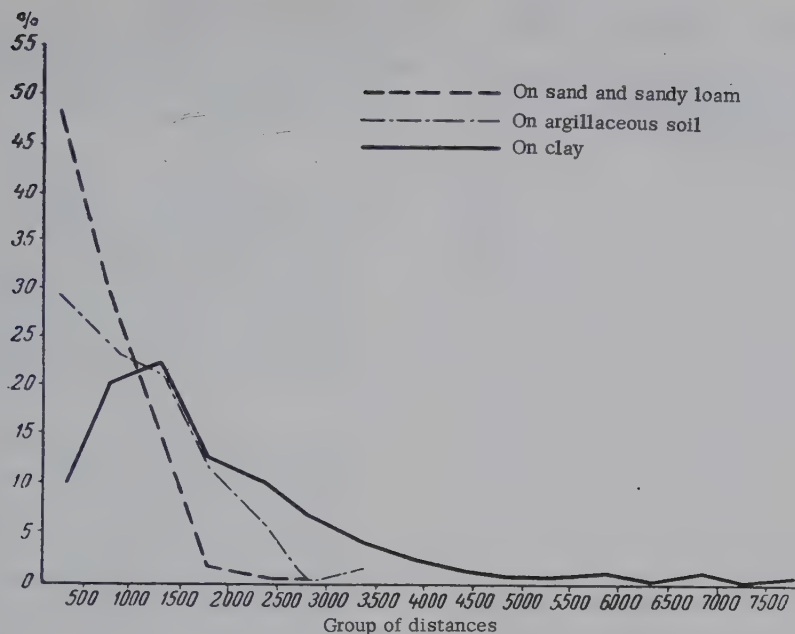


FIGURE 4. Mean distribution graph for Haloxylon (from measurements taken on the ground)

graph, except that the photograph-based graph shows a second peak in the range from 0 m to 5 m. But these secondary differences cannot disprove the fact that measurement on photographs produced the same three groups of graphs which may easily be distinguished from each other.

Distribution graphs prepared from photographs may be utilized by geobotanists in determining lithologic contacts on the basis of the density and distribution of Haloxylon plants.

In preparing a lithologic map of early alluvial deposits, we divided the entire territory to be mapped from photographs into areas which differed from each other chiefly in the distribution, luxuriance and thickness of Haloxylon growth. This first division was done by visual estimate and therefore was somewhat subjective. Later, traverses were established by which studies were made of a number of sections, and distribution graphs were prepared by measuring the photographs. Comparison of graphs for the various points made it possible to determine the extent to which the distribution of Haloxylon was homogeneous within an outlined contour. This in turn, allowed corrections of the original boundaries to give them a more objective character. This material was correlated with information obtained from ground investigations and corrections made.

This method, along with the data obtained from a broad grid of trenches, made it possible to prepare a lithologic map of early alluvial deposits with an acceptable degree of accuracy.

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# Letters to Editor

## LETTER TO THE EDITOR

The criticism by Salih Faizi in the November issue of the *International Geology Review* (v. 2, no. 11, p. 1006-1007, 1960) of the quality of the AGI-sponsored translations of the "Izvestiya" and "Doklady" is unfortunately amply justified, and he has put his finger on the source of the difficulty when he says that the translations "seem to be prepared by people with little, if any, knowledge in geology, especially the Russian usage of geological terms."

The only possible way to avoid these errors, which detract so much from the usefulness of the present product, would be to have each paper translated, or at least painstakingly reviewed, by someone who is an expert in the particular field of geology concerned and who can also read Russian. In view of the degree of specialization within the earth sciences today it is impossible for any one individual to be sufficiently familiar with the more esoteric jargon in all fields and in both languages to translate papers in a wide range of fields with equal accuracy. This is illustrated in Dr. Faizi's own remarks.

In speaking of the 55-page paper containing detailed petrographic descriptions of 17 rock varieties, which he thought should have been boiled down to 5 pages, Dr. Faizi says, "One learns from the details that quartz contains gas inclusions and shows wavy extinction, that chlorite is pleochroic, etc. -- facts known to occur everywhere."

It is perfectly true that Russian authors are unnecessarily verbose and repetitious; but although Dr. Faizi is apparently on firm ground when it comes to stratigraphy, I cannot help wondering if a petrographer might not possibly find a little more significance in the details that are dismissed so casually. The presence or absence of wavy (or "undulose", but not "wavy") extinction and the alignment, if any, of the gas bubbles in quartz may have definite petrogenetic implications; even the pleochroism of chlorite, by its intensity, might be a clue to its chemical composition. A striking similarity in 17 different rocks, if the descriptions were indeed so repetitious, may in itself be interesting. Only a translator who knows as much or more about the subject than the author can judge how much of the detail is justified.

That particular case was used as an argument for improved abstract coverage rather than cover-to-cover translations. Better abstract coverage is greatly to be desired in its own right, but no abstract can substitute for the complete paper. The real purpose of an ab-

stract — unfortunately too often lost sight of — is to draw attention to a work so that the reader who is particularly interested can seek out the original, and unless he can read that original himself he still needs a translation by a competent translator. It is an incontrovertible fact that there simply are not now enough translators and abstracters who come anywhere near meeting the ideal requirements. Of the small number who are so qualified, only a few are available for such work, or are willing to work for the comparatively meager financial return offered by the cover-to-cover translation projects. The present translations are as good as we can hope for under prevailing conditions.

I believe that the most positive contribution AGI can make toward improvement of the situation would be to take the long view and use all its influence, first, to encourage the present generation of geology students to study foreign languages early and use them often, until they can read geological material without having to look up very many words per page (the technical literature in a foreign language, extremely formidable to the layman, is actually easier than any other type of reading for one who already knows the terminology in his own language); and second, to join forces with other professional groups to promote the teaching of languages at the high school and elementary school level so that future generations of scientists — not to mention diplomats and others who have need of languages — will be better equipped linguistically.

The advantage of having a large body of earth scientists who can read foreign languages is twofold. The individual who can communicate directly with the author has an advantage over users of translations in terms of time, money, and accuracy. At the same time, the existence of a greater potential supply of really qualified translators, covering among them all branches of geology, ought to result in a noticeable improvement in the quality of translations.

In this connection, a possible source of geological translators and abstracters might lie in geologically trained women. Many of these abandon their careers in favor of marriage or change fields for lack of employment opportunities. Translating and abstracting can very often be done at home under flexible part-time arrangements, making it very suitable work for housewives and mothers. Might it not be worthwhile to encourage women who take higher degrees in geology to develop language skills on the side?

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(3, Jan. 1961)

<sup>1</sup>Publication authorized by the Director.



# Review Section

ARAL SEA AND ITS SEDIMENTS, based mainly on material from: Strakhov, N. M., Brodskaya, N. B., Knyazeva, L. M., Razzhivina, A. N., Rateev, M. A., Sapozhnikov, D. G., and E. S. Shishova. FORMATION OF SEDIMENTS IN RECENT BASINS: A symposium, Izd. Akad. Nauk SSSR, Moscow, 1954, 791 pp. A summary by George V. Chilingar,<sup>2</sup> Univ. of Southern Calif.

## INTRODUCTION

The Aral Sea has an area of 63, 600 km<sup>2</sup> (without islands), whereas the area of its drainage basin (fig. 1) is equal to 446, 000 km<sup>2</sup>. Thus the ratio of drainage area to sea area is around 7. The morphology of the bottom places the Aral Sea in a typical "flat-shallow basin" category. The depths of the deeper western

part of the basin (narrow, elongated depression, probably of tectonic origin) range from 40 to 68 m. The eastern and the larger part of the basin has a maximum depth of 25 m and is quite flat and symmetrical. The delta of Syr-Dar'ya River is situated in the northeastern part of the Aral Sea, whereas the delta of Amu-Dar'ya is located in the southern part of the sea.

The clockwise currents of the Aral Sea are shown in Figure 2, and the salinity of surface layer of water is presented in Figure 3. The



FIGURE 1. Drainage basin of Aral Sea (after Brodskaya, 1954, p. 239)



FIGURE 2. Aral Sea currents (1936-1937), symposium vol., p. 240



FIGURE 3. Variation in salinity of surface water layer in Aral Sea (after M.V. Fedosov, in Alekin, 1953, p. 268)

- Less than 8 o/oo (parts per thousand)
- Less than 9 o/oo
- Less than 10 o/oo
- 10 to 10.5 o/oo, and
- Higher than 10.5 o/oo.

<sup>1</sup>Obrazovaniye osadkov v sovremennykh vodoyemnykh; Akademiya Nauk SSSR Institut geologicheskikh nauk,

<sup>2</sup> This is the third summary by Prof. Chilingar from this symposium volume to appear in IGR. The Caspian Sea and its sediments appeared in vol. 1 no. 1, pp. 105-111; the Black Sea and its sediments, in vol. 1, no. 3, pp. 74-81.--M.R.

## REVIEW SECTION

wave disturbance is quite significant and extends down to a depth of 10-15 m. The water, however, is very transparent probably due to the rapid coagulation of suspended matter, which is brought by the rivers in large amounts. The total salinity of Aral Sea water is around 1 percent, and the variation in salinity of surface layer (fig. 3) is controlled by the influx of river waters and evaporation.

### CHEMISTRY OF ARAL SEA WATER

The ionic composition of Aral Sea water (in parts per thousand) is as follows:

$\text{Na}^+$  -- 2.263,  $\text{K}^+$  -- 0.081,  $\text{Mg}^{2+}$  -- 0.490,  $\text{Ca}^{2+}$  -- 0.556,  $\text{Cl}^-$  -- 3.502,  $\text{Br}^-$  -- 0.0025,  $\text{SO}_4^{2-}$  -- 3.130, and  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  -- 0.194.

In percent equivalents this would correspond to 28.39, 0.99, 13.61, 6.88, 30.10, trace, 19.11 and 1.15, respectively (after F. F. Bader, in Alekin, 1953). The  $\text{CaSO}_4$ ,  $\text{MgSO}_4$ ,  $\text{KCl}$ ,  $\text{NaCl}$ ,  $\text{MgCl}_2$ , and  $\text{CaCO}_3$  contents (in percent of total salts) in Aral Sea are 12.91, 25.80, 1.87, 56.72, 1.36, and 1.30 percent, respectively. The examination of the above figures indicates a low chloride and high sulfate content. Thus, the saturation of water with respect to gypsum occurs only at a salinity of 3 percent. The alkalinity of the near-shore zones of the basin is not high and is equal to 2.3-2.4 mg-equiv. The maximum alkalinity values are recorded in the northern bays of the sea -- 2.9 to 3.0 mg-equiv. (fig. 4).

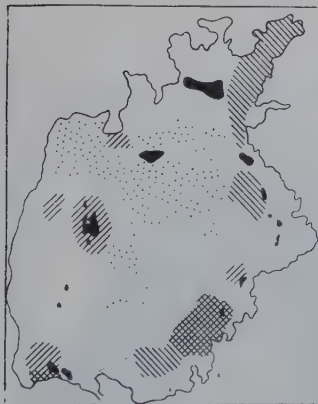


FIGURE 4. Distribution of alkalinity in surface water layers of Aral Sea (after M. V. Fedosov, in Alekin, 1953, p. 273)

- negative  
 - up to 2  
 - higher than 2  
 - higher than 3

The Aral Sea water is usually supersaturated with  $\text{CaCO}_3$  (2 - 2.5 times), which results in its chemical precipitation. The pH of water varies from 7.8 to 8.0; and during the summer months

the water is saturated (and sometimes supersaturated) with oxygen. The amount of  $\text{CaCO}_3$  in suspended matter brought by the Amu-Dar'ya River is around 18 percent, whereas the amount of  $\text{CaCO}_3$  in solution is equal to 125 mg/L. The iron content in Amu-Dar'ya waters is about 1 mg/L. Thus, the amounts of  $\text{CaCO}_3$  and Fe brought in annually by this river are:

|               | $\text{CaCO}_3$ |          | Fe        |          |
|---------------|-----------------|----------|-----------|----------|
|               | Tons            | Per cent | Tons      | Per cent |
| In solution   | 5,256,000       | 23       | 42,050    | 1        |
| In suspension | 17,406,000      | 77       | 3,868,000 | 99       |

The same analysis for the Syr-Dar'ya River shows the following results:

|               | $\text{CaCO}_3$ |          | Fe      |          |
|---------------|-----------------|----------|---------|----------|
|               | Tons            | Per cent | Tons    | Per cent |
| In solution   | 2,023,500       | 40       | 13,490  | 3        |
| In suspension | 2,774,000       | 60       | 440,000 | 97       |

### SEDIMENTS OF THE ARAL SEA

The amounts of sediments brought into the Aral Sea have been calculated by G. V. Lopatin (1950, in Brodskaya, 1954<sup>3</sup>, p. 241) and are presented in Table 1.

The sediments of the Aral Sea comprise 1) sands, 2) calcareous oölitic sands, 3) silty muds, 4) clayey muds, and 5) clayey-calcareous (marly) muds. This distribution of various sediments is presented in Figures 5 through 15; whereas the granulometric and chemical composition of these sediments is shown in Tables 2 through 17.

TABLE 1. Annual influx of sediments into Aral Sea in million tons

| Source of sediments | Brought by rivers in - |          |          |                               | Atmospheric transportation           |                            | Total  |
|---------------------|------------------------|----------|----------|-------------------------------|--------------------------------------|----------------------------|--------|
|                     | suspension             | traction | solution | Products of shore destruction | Salts from atmospheric precipitation | Sediments brought by winds |        |
| Amu-Dar'ya R.       | 96.7                   | 4.84     | 18.37    | -                             | -                                    | -                          | -      |
| Syr-Dar'ya R.       | 12.14                  | 0.6      | 5.56     | -                             | -                                    | -                          | -      |
| Total influx        | 108.84                 | 5.44     | 23.93    | 6.0                           | 1.40                                 | 8.66                       | 154.27 |

<sup>3</sup> The Strakhov, Brodskaya et al. symposium volume itself is referred to throughout this summary as "Brodskaya, 1954" after the principal author of the section of the volume being summarized. --M.R.



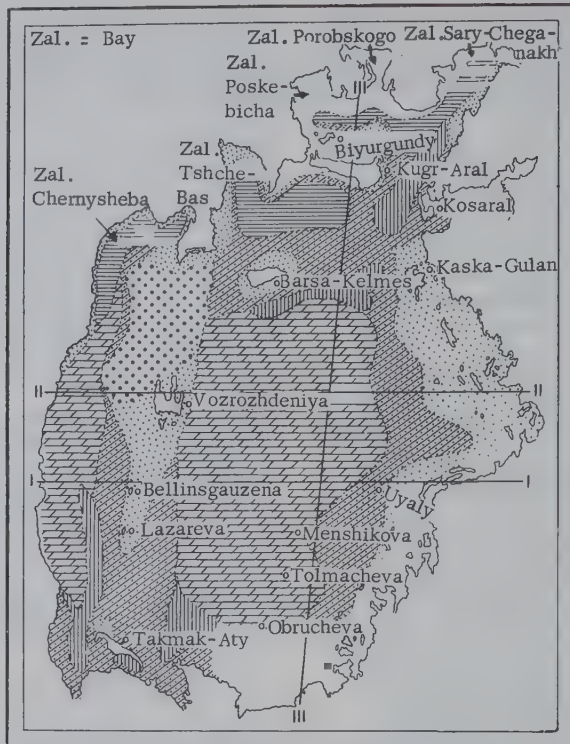


FIGURE 5. Aral Sea sediments, symposium volume, p.246

- sands
- silty muds
- calcareous-clayey muds
- clayey muds of northern bays
- clayey muds of deltas
- oolites, and
- ancient horizons

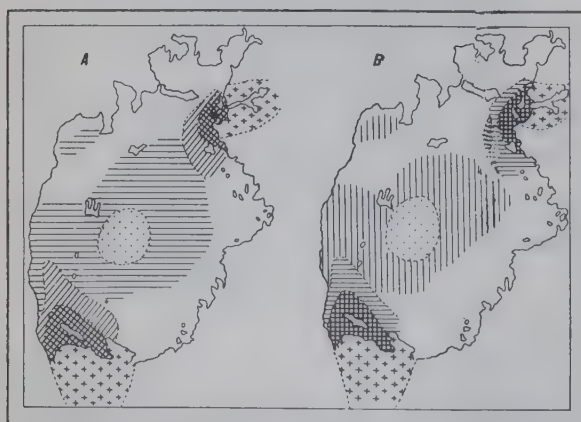


FIGURE 6. Distribution of absolute amounts of  $\text{CaCO}_3$  (A) and clastic material (B) deposited during the latest stage of history of Aral Sea (after N. M. Strakhov, symposium volume, p. 254.)

- deltaic deposits
- areas of maximum  $\text{CaCO}_3$  accumulation, and
- areas of maximum accumulation of clastic material



FIGURE 7. Distribution of sand particles greater than 0.1 mm in diameter (in percent of insoluble residue), symposium volume, p.255 (See Figure 5 for transliterated place names)





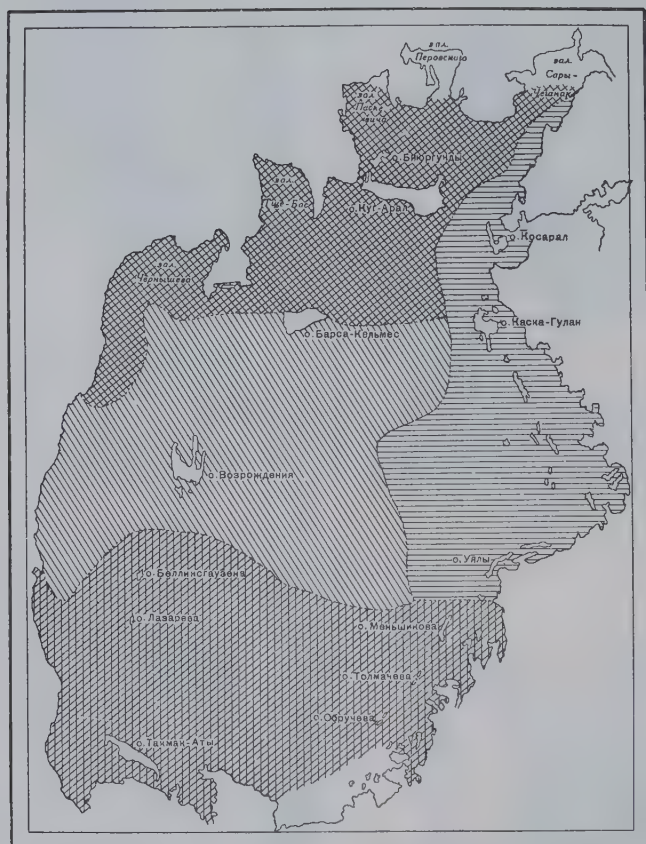






FIGURE 12. Coloration of Aral Sea sediments, after Brodskaya, 1954, p. 262

- |   |   |
|---|---|
|  - greenish        |  - reddish brown |
|  - yellowish-brown |  - light gray    |

(See Figure 5 for place names)

## REVIEW SECTION

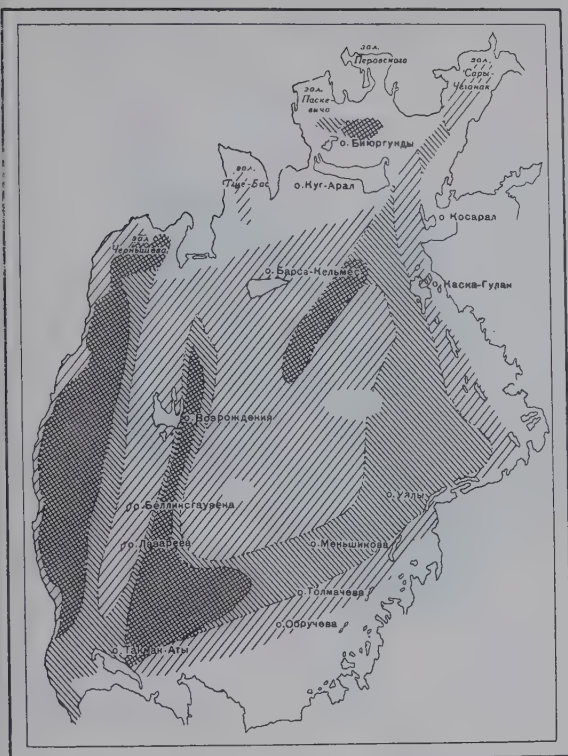
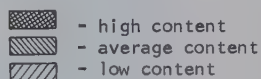


FIGURE 13. Distribution of diatoms in Aral Sea sediments, after Brodskaya, 1954, p. 272



(See Figure 5 for place names)

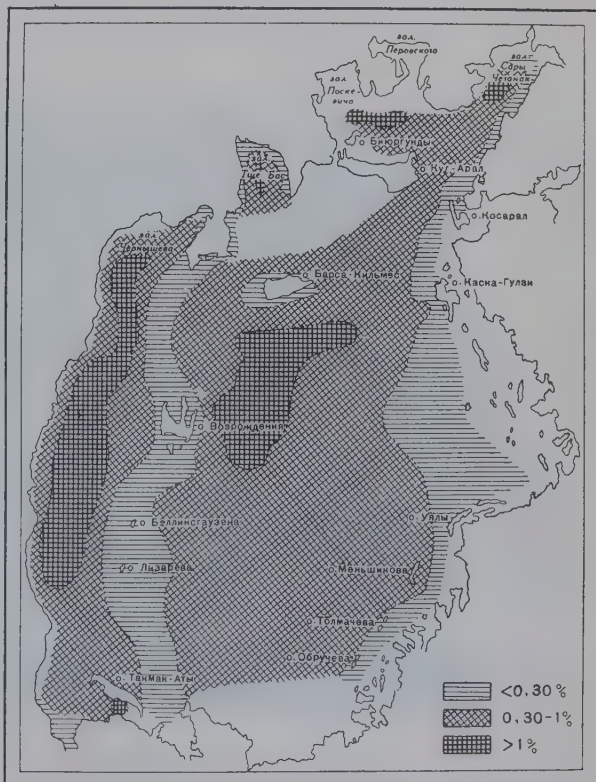


FIGURE 14. Distribution of organic carbon in Aral Sea sediments (in percent of sediment), after Brodskaya, 1954, p. 274.

(See Figure 5 for place names)



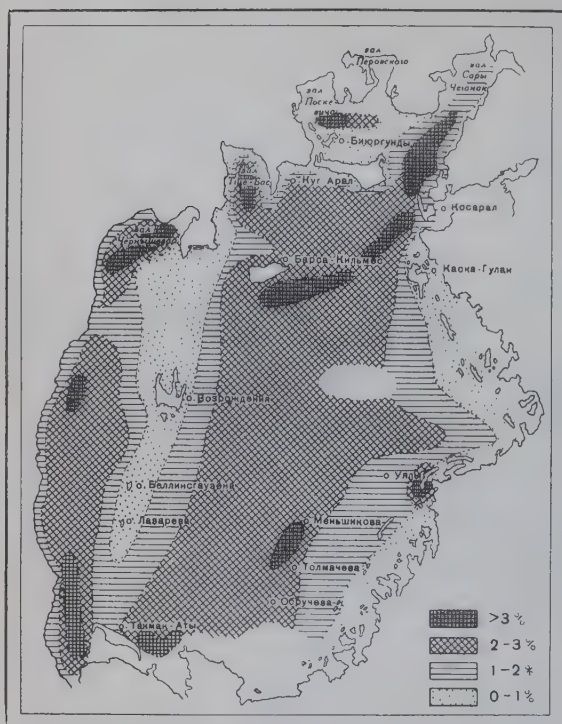


FIGURE 15. Distribution of Iron (in percent of sediment) in Aral Sea sediments, after Brodskaya, 1954, p. 277  
(See Figure 5 for place names)

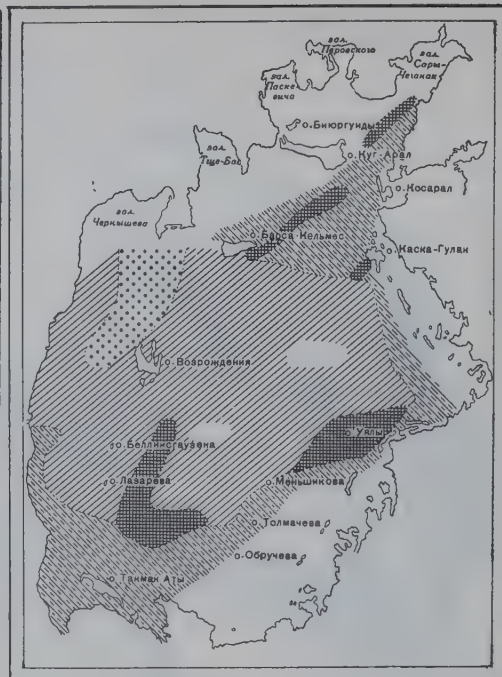






FIGURE 16. Distribution of various morphological types of carbonates in Aral Sea, after Brodskaya, 1954, p. 270

-  - zone of predominating clastic carbonate material
  -  - area where the carbonate material of chemical origin predominates
  -  - areas with major amounts of chemical and clastic carbonate material
  -  - oölite zone
- (See Figure 5 for place names)

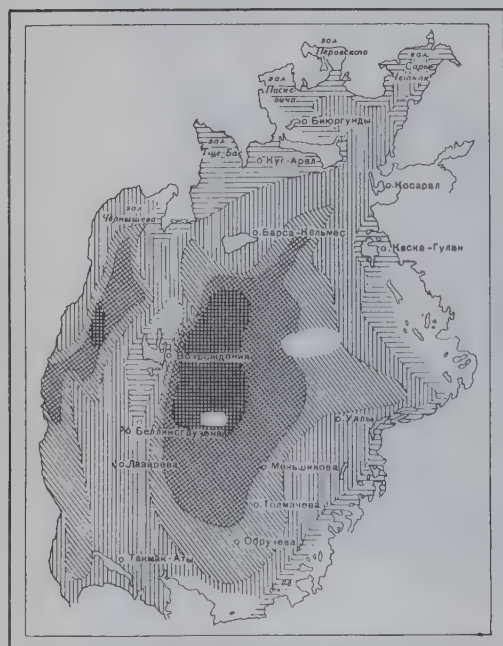








FIGURE 17. Content of carbonates in sediments of Aral Sea, after Brodskaya, 1954, p. 268

-  - less than 10 percent  
 - 10 to 30 percent  
 - 30 to 40 percent  
 - 40 to 50 percent  
 - more than 50 percent  
 - areas devoid of recent sediments.  
 (See Figure 5 for place names)

## REVIEW SECTION

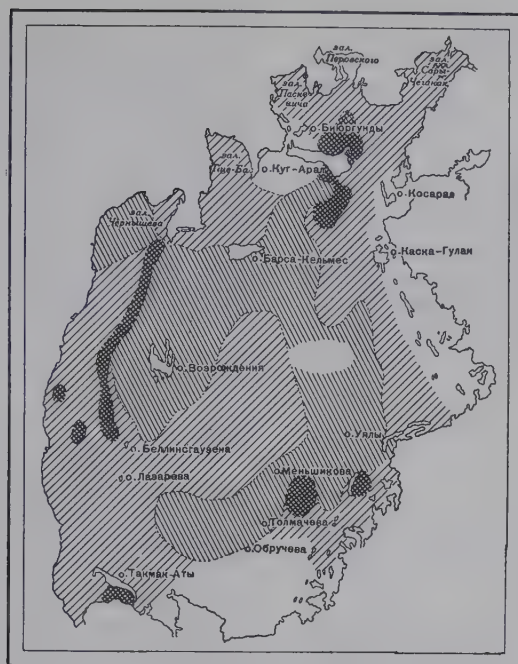






FIGURE 18. Distribution of shell material on Aral Sea bottom, after Brodskaya, 1954, p.264

-  - low content
-  - average content
-  - high content
-  - outcrops of ancient horizons

(See Figure 5 for place names)

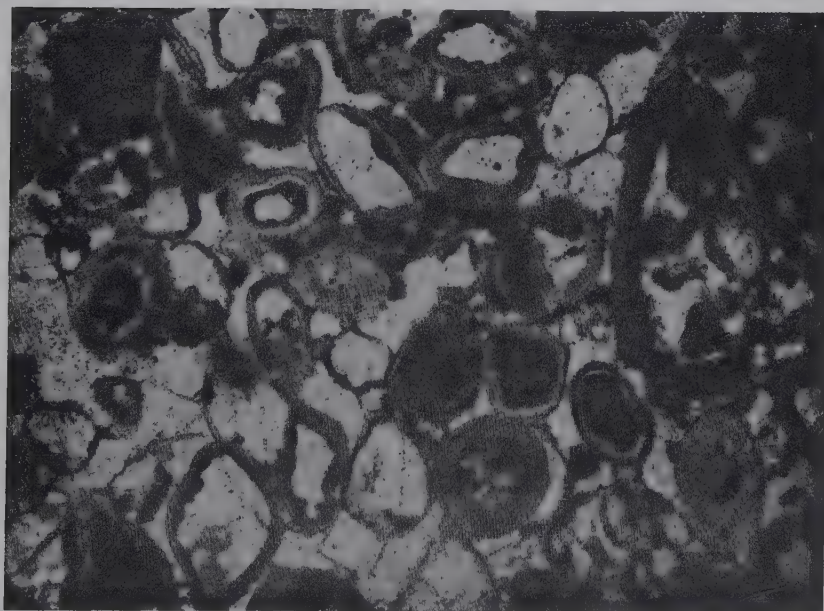


FIGURE 19. Aral Sea oölites, x 90, without analyzer, after Brodskaya, 1954, p. 264-5, Figure 94



# INTERNATIONAL GEOLOGY REVIEW

TABLE 2. Granulometric composition of sands (in percent)

| Grade size, mm | Number of analyses | Range      | Average content |
|----------------|--------------------|------------|-----------------|
| Larger than 2  | 8                  | 0.1 - 0.8  | 0.16            |
| 2-1            | 8                  | 0.8 -16.3  | 0.62            |
| 1-0.5          | 8                  | 5.6 -85.7  | 8.20            |
| 0.5-0.25       | 8                  | 26.7 -85.7 | 27.40           |
| 0.25-0.1       | 8                  | 26.7 -89.6 | 50.70           |
| 0.1-0.05       | 6                  | 0.22-28.4  | 10.43           |
| 0.05-0.01      | 6                  | 0.22- 0.69 | 0.54            |
| Less than 0.01 | 6                  | 0.22- 8.61 | 3.67            |

TABLE 6. Grain size distribution of silty muds

| Diameter, mm    | Number of analyses | Weight percent of components |                 |
|-----------------|--------------------|------------------------------|-----------------|
|                 |                    | Range                        | Average content |
| Larger than 0.1 | 7                  | 0.1-28.7                     | 18.2            |
| 0.1-0.05        | 7                  | 0.1-41.5                     | 34.88           |
| 0.05-0.01       | 7                  | 1.0-61.2                     | 26.15           |
| Less than 0.01  | 7                  | 6.0-42.0                     | 24.6            |
| 0.1-0.001       | 5                  | 8.8-20.1                     | 11.6            |
| Less than 0.001 | 5                  | 3.6-29.8                     | 14.2            |

TABLE 3. Chemical composition of sands (in percent)

| Component         | Number of analyses | Range    | Average content |
|-------------------|--------------------|----------|-----------------|
| Insoluble residue | 13                 | 77-91    | 84.79           |
| CaCO <sub>3</sub> | 13                 | 9-23     | 15.21           |
| C <sub>org</sub>  | 10                 | 0.08-1.2 | 0.12            |
| Fe                | 9                  | 0.5 -1.7 | 0.88            |

TABLE 7. Chemical composition of silty muds

| Component         | Number of analyses | Weight percent of components |                 |
|-------------------|--------------------|------------------------------|-----------------|
|                   |                    | Range                        | Average content |
| Insoluble residue | 17                 | 73.4-86.8                    | 80.31           |
| CaCO <sub>3</sub> | 17                 | 11.4-26.6                    | 19.69           |
| C <sub>org</sub>  | 17                 | 0.1- 1.0                     | 0.35            |
| Fe                | 15                 | 0.3- 3.0                     | 1.87            |

TABLE 4. Granulometric composition of calcareous sands (in percent)

| Grade size, mm | Number of analyses | Range     | Average content |
|----------------|--------------------|-----------|-----------------|
| Larger than 2  | 5                  | 0.4- 1.2  | 0.8             |
| 2-1            | 3                  | 0.8- 1.7  | 1.23            |
| 1-0.5          | 3                  | 15.2-24.1 | 19.5            |
| 0.5-0.25       | 3                  | 37.6-42.2 | 41.3            |
| 0.25-0.1       | 3                  | 19.2-42.4 | 30.9            |
| 0.1-0.05       | 3                  | 0.6- 8.2  | 3.66            |
| 0.05-0.01      | 3                  | 0.2- 3.1  | 1.3             |
| Less than 0.01 | 3                  | 0.3- 1.6  | 1.0             |

TABLE 8. Grain size distribution of deltaic clayey muds

| Diameter, mm    | Number of analyses | Weight percent of size groups |                 |
|-----------------|--------------------|-------------------------------|-----------------|
|                 |                    | Range                         | Average content |
| Larger than 0.1 | 5                  | 0.1-1.2                       | 0.6             |
| 0.1-0.05        | 5                  | 0.2-17.3                      | 11.2            |
| 0.05-0.01       | 5                  | 10.3-42.5                     | 22.6            |
| Less than 0.01  | 5                  | 50.5-75.9                     | 65.4            |
| 0.01-0.001      | 5                  | 41.8-65.6                     | 51.5            |
| Less than 0.001 | 5                  | 7.1-19.6                      | 10.7            |

TABLE 5. Chemical composition of calcareous sands (in percent)

| Component         | Number of analyses | Range       | Average content |
|-------------------|--------------------|-------------|-----------------|
| Insoluble residue | 6                  | 34.9 -72.7  | 54.91           |
| CaCO <sub>3</sub> | 6                  | 27.2 -65.10 | 45.1            |
| C <sub>org</sub>  | 5                  | 0.18- 0.44  | 0.29            |
| Fe                | 5                  | 0.17- 0.6   | 0.41            |

TABLE 9. Chemical composition of deltaic slightly calcareous muds

| Component         | Number of analyses | Weight percent of components |                 |
|-------------------|--------------------|------------------------------|-----------------|
|                   |                    | Range                        | Average content |
| Insoluble residue | 9                  | 71.2 -77.3                   | 76.46           |
| CaCO <sub>3</sub> | 9                  | 18.7 -28.06                  | 23.54           |
| C <sub>org</sub>  | 7                  | 0.3 - 1.46                   | 0.61            |
| Fe                | 7                  | 3.34- 3.86                   | 3.58            |

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TABLE 10. Grain size distribution of clayey muds of northern bays

| Diameter, mm    | Number of analyses | Weight percent of size groups |         |
|-----------------|--------------------|-------------------------------|---------|
|                 |                    | Range                         | Average |
| Larger than 0.1 | 4                  | 0.1- 1.0                      | 0.7     |
| 0.1-0.05        | 4                  | 0.6- 4.8                      | 2.2     |
| 0.05-0.01       | 4                  | 8.3-30.4                      | 18.9    |
| Less than 0.01  | 4                  | 67.2-91.0                     | 78.2    |
| 0.01-0.001      | 4                  | 46.6-65.3                     | 56.8    |
| Less than 0.001 | 4                  | 8.3-44.4                      | 21.3    |

TABLE 11. Chemical composition of clayey muds of northern bays

| Component         | Number of analyses | Weight percent of components |         |
|-------------------|--------------------|------------------------------|---------|
|                   |                    | Range                        | Average |
| Insoluble residue | 11                 | 75.4 -95.1                   | 87.67   |
| CaCO <sub>3</sub> | 11                 | 4.89-24.53                   | 12.33   |
| Corg              | 6                  | 0.3 - 1.56                   | 0.82    |
| Fe                | 10                 | 2.1 - 5.3                    | 3.98    |

TABLE 12. Grain size distribution of clayey-calcareous muds

| Diameter, mm    | Number of analyses | Weight percent of size groups |         |
|-----------------|--------------------|-------------------------------|---------|
|                 |                    | Range                         | Average |
| Larger than 0.1 | 12                 | 0.2- 1.6                      | 0.6     |
| 0.1-0.05        | 12                 | 0.2- 4.1                      | 1.74    |
| 0.05-0.01       | 12                 | 4.9-32.7                      | 14.6    |
| Less than 0.01  | 12                 | 62.6-94.3                     | 83.1    |
| 0.01-0.001      | 12                 | 45.4-75.4                     | 58.06   |
| Less than 0.001 | 12                 | 9.3-42.3                      | 24.9    |

TABLE 13. Chemical composition of clayey-calcareous muds

| Component         | Number of analyses | Weight percent of components |         |
|-------------------|--------------------|------------------------------|---------|
|                   |                    | Range                        | Average |
| Insoluble residue | 21                 | 43.3 -70.3                   | 58.47   |
| CaCO <sub>3</sub> | 21                 | 31.10-51.98                  | 41.53   |
| Corg              | 17                 | 0.58- 1.31                   | 0.84    |
| Fe                | 21                 | 1.8 - 3.17                   | 2.47    |

TABLE 14. Organic carbon content in various sediments of Aral Sea

| Sediments                    | Number of analyses | Weight percent of Corg. |         |
|------------------------------|--------------------|-------------------------|---------|
|                              |                    | Range                   | Average |
| Sands                        | 10                 | 0.07-1.1                | 0.12    |
| Calcareous sands             | 5                  | 0.1 -0.4                | 0.29    |
| Silty muds                   | 17                 | 0.1 -1.0                | 0.35    |
| Deltaic clayey muds          | 7                  | 0.3 -1.4                | 0.61    |
| Clayey muds of northern bays | 6                  | 0.3 -1.56               | 0.82    |
| Clayey-calcareous muds       | 17                 | 0.4 -1.3                | 0.84    |

TABLE 15. Iron content in various sediments of Aral Sea

| Sediments                    | Number of analyses | Weight percent of Fe |         |
|------------------------------|--------------------|----------------------|---------|
|                              |                    | Range                | Average |
| Sands                        | 10                 | 0.23-1.7             | 0.88    |
| Calcareous sands             | 5                  | 0.17-0.6             | 0.41    |
| Silty muds                   | 15                 | 0.3 -3.0             | 1.87    |
| Deltaic clayey muds          | 7                  | 3.3 -3.8             | 3.58    |
| Clayey muds of northern bays | 10                 | 2.1 -5.3             | 3.88    |
| Clayey-calcareous muds       | 21                 | 1.8 -3.17            | 2.47    |

TABLE 16. Average content of manganese in various sediments of the Aral Sea

| Sediments              | Average Mn content, percent |
|------------------------|-----------------------------|
| Sands                  | 0.026                       |
| Silty muds             | 0.037                       |
| Clayey muds            | 0.07                        |
| Clayey-calcareous muds | 0.046                       |

TABLE 17. Average content of phosphorus in various sediments of Aral Sea

| Sediments              | Average P content, percent |
|------------------------|----------------------------|
| Sands                  | 0.063                      |
| Silty muds             | 0.1                        |
| Clayey muds            | 0.16                       |
| Clayey-calcareous muds | 0.14                       |



As shown in Figure 14 and Table 14, the maximum amount of organic carbon, the major part of which is brought in by the rivers, occurs in the fine-grained sediments (0.84 percent); and its minimum content is in sands (0.12 percent).

## GENETIC TYPES OF CARBONATES IN ARAL SEA SEDIMENTS

Figures 16, 17, and 18 show the distribution of carbonate deposits, which comprise

- 1) oölites
- 2) biogenetic (organic) carbonate, and
- 3) pelitomorphous carbonate.

The oölites, which are shown in Figure 19, are composed mainly of aragonite. A sudden change in temperature apparently favors the formation of oölites, as the cold currents from the western deeps flow over the shallow warm parts of the basin. It is interesting to note that the oölite zone occurs where the current changes its direction (turns).

The protective and skeletal structures of organisms which contribute to the organic carbonate deposits are not numerous -- 6 species of ostracods and foraminifers and 8 species of molluscs. The carbonates of organic origin constitute about 12-18 percent of the total carbonate deposits.

The pelitomorphous carbonate material is mainly of mechanical origin (60-65 percent of total carbonates), whereas the remainder of pelitomorphous carbonates (acicular needles) is of chemical origin and constitutes about 17-28 percent of the total carbonate material. The reviewer obtained needles similar to those described by Brodskaya, p. 266) on precipitation out of sea water. Sometimes these "needles" grow in bundles.

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# Reference Section

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A major function of the AGI translations program is the screening of foreign literature for material that should be made available to the English-speaking scientist. Researchers who need such material are urged to review these lists and send us their recommendations for consideration by the editors; the translation needs of all geologists will be served better thereby.

-- Managing Editor

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## REFERENCE SECTION

### RECENT TRANSLATIONS IN GEOLOGY

A review of the Translation Services

This part of the Reference Section is devoted each month to a listing of the new translations of geologic significance which have become available from sources other than IGR and the established cover-to-cover journals in geology. This is done to accomplish several purposes:

- 1) inform geologists of the foreign literature in their field available in translation;
- 2) provide information necessary to avoid duplication of translation effort, and
- 3) advise geologists of the activities of the various organizations providing translations or related services in their field.

Attention is called to a new service of the journal *Economic Geology*, which in its January-February 1961 issue (vol. 56, no. 1, pp. 219-235), began systematic review of the relatively new Russian journal, *Geologiya Rudnykh Mestorozhdenii*, [Geology of Ore Deposits], (vol. 1, no. 1, January-February 1959.) Regular reviews of this journal will appear in *Economic Geology* as a project supported by the National Science Foundation.

This month's listings include two new sources in addition to those which appeared in the January 1961 issue of IGR (vol. 3, no. 1, pp. 88-89) and the March 1961 issue (vol. 3, no. 3, p. 270). They are:

|        |  |
|--------|--|
| CEA    | Commissariat a l'Energie atomique<br>S. A. R. L. DUNOD<br>92, Rue Bonaparte<br>Paris (6 <sup>e</sup> ), France |
| INSDOC | Insdoc<br>National Physical Laboratory of India<br>Hillside Road<br>New Delhi 12, India                        |

Geologists and translators are invited to send announcements of geologic translations which have not been cited by the sources from which these lists are prepared. The submittal of a copy of a translation will be construed as an offer for IGR to publish, or make copies available and/or turn the copy over to a major translations repository at our discretion. Suggestions for improving this service are welcomed.

### COVER-TO-COVER JOURNALS OF INTEREST TO GEOLOGISTS

Material in the following translation journals are not included in the subsequent listing of recent translations.

Atomic Energy, published by Consultants Bureau.

Bulletin (Izvestiya) of the Academy of Sciences USSR, Geophysics Series, published by the American Geophysical Union.

Doklady of the Academy of Sciences of the U. S. S. R., Earth Sciences Sections (Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, lithology, and permafrost), published by the American Geological Institute.

Geochemistry, published by the Geochemical Society.

Geodesy and Cartography, published by American Geophysical Union.

Izvestiya of the Academy of Sciences of the U. S. S. R., Geologic Series, published by the American Geological Institute.

Petroleum Geology, published by the Review of Russian Geology.

Problems of the North, published by the National Research Council, Canada.

Soil Science, published by the American Institute of Biological Sciences.

Soviet Geography, selected translations and reviews published by the American Geographic Society.

Soviet Physics: Crystallography, published by The American Institute of Physics.

### RECENT TRANSLATIONS

The current list is drawn from the following sources:

Technical Translations, vol. 5, nos. 3, 4, and 5.

AEC Translations List, Jan 20, 1961

In respect to this latter source, it should be pointed out that a number of the AEC listings are in French; they have not been translated to English. Those ordering from LC or SLA (Library of Congress and Special Libraries Association, John Crerar Library) should specify "microfilm" (mi) or "photocopy" (ph) when ordering, as the price for the two is often the same. The film requires a viewer or reproduction means.

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## REFERENCE SECTION

### DICTIONARIES, GLOSSARIES, AND SOURCES OF MATERIAL FOR TRANSLATING RUSSIAN GEOLOGY

Geologists are becoming aware to an increasing degree of the need to follow Russian research. While the supply of translations is ever increasing, there remains the need for the geologist himself to know something of the problem of tackling the original. Russian is rapidly becoming a "must" scientific language for the American geologist.

Some are content to read for themselves; others are willing to put forth the extra effort required to translate technical Russian into English which is not only readable but correct in its terminology. To aid both these groups, International Geology Review offers a listing of some of the dictionaries and glossaries currently available, a brief evaluation of them, and some hints on how to secure Russian material.

For the neophyte, some knowledge of Russian grammar is indispensable. The highly inflected nature of the language allows Russian writers rather free rein in inverting sentences and inserting qualifying phrases. The Russian idiom also frequently twists a negative phrase into a positive meaning.

Assuming an understanding of basic Russian, we present the following roundup of sources and source materials. Books not currently available either through bookstores or libraries, no matter how good they be, are not included.

As a basic, general two-way dictionary, seasoned translators prefer A. I. Smirnitsky's Russian-English Dictionary, currently available in two editions:

Fourth edition, Gosudarstvennoe izdatelstvo,  
Moscow, 1959, \$6.00  
Third edition, E. P. Dutton Co., Inc.,  
New York, 1959, \$6.95.

The Russian and American editions tally page-for-page. The Dutton version has slightly smaller type, apparently because of a photo-reduction process from the original plates, and hence is slightly less easy to read. On the other hand, both paper and binding of the American book are superior.

For technical terminology, professional translators now rely to a great degree on Ludmilla Ignatieff Callagham's Russian-English Technical and Chemical Dictionary, John Wiley and Sons, Inc., New York, 1947. In the opinion of Eugene A. Alexandrov, member of AGI's Translation Committee, the Callagham dictionary contains only 67 percent of the terms encountered in general geology. Alexandrov notes that the author "evidently has a not quite adequate knowledge in the field of earth sciences. This is indicated by a series of erroneous translations of Russian geological terms. In

some instances Callagham does not give the English equivalent of a Russian term and substitutes his own free-style interpretation."

Mark E. Burgunker's Russian-English Dictionary of Earth Sciences. (Telberg Book Co., 544 Sixth Avenue, New York 11, N. Y.) has just appeared. The 94-pages (average 20 terms per page) contain nomenclature for general geologic features (gully, barrier reefs, undrained lakes), mixed with biologic terminology (bamboo, banana, plankton). Two definitions are sometimes given, in addition to the source branch of science. The work contains no verbs, no idiomatic phrases other than multi-word terms (mean specific gravity of the earth), and only the broadest geologic time terms.

This points up the importance of a good source of geological terms in English. The new AGI Glossary of Geology and Related Sciences, with Supplement (1960) adds 4,296 terms to the 1957 glossary. In lieu of an adequate source-book, the reader of Russian geologic literature is often forced to "play his hunches", and such a technical reference is needed to check suspected transliterations.

One professional translator with geologic background spent a week looking for the translation of "gelifluktsiya". He finally found it in an article on permafrost. The glossary supplement would have verified his hunch in a few seconds.

All-Russian dictionaries may be of considerable help. The supply of glossaries for special fields (petroleum geology, crystallography, etc.) is so variable, however, that we will indicate their sources instead. Many bookstores frequently publish catalogs and Victor Kamkin recently released an 8-page list devoted to geologic literature, including special glossaries now on their shelves. One warning: although these special glossaries are usually reliable in terminology, they are English-to-Russian, and their value is sharply decreased if they do not have a reverse index.

Here is an alphabetic list of bookstores and magazine agencies from which Russian scientific literature may be purchased or ordered:

Four Continents Book Corporation,  
822 Broadway,  
New York 3, N. Y.

Imported Publications and Products  
4 West 16th Street  
New York 11, N. Y.

Moore-Cattrell Subscription Agencies, Inc.  
North Coshocton, N. Y.

Stechert-Hafner, Inc.  
31 East Tenth Street  
New York 11, N. Y.

Telberg Book Co.,  
544 Sixth Avenue  
New York 11, N. Y.

Universal Distributors  
52-54 West Thirteenth Street  
New York 11, N. Y.

Victor Kamkin, Inc.  
2906 Fourteenth Street, N. W.  
Washington 9, D. C.

It should be explained that these stores depend on Moscow for their shipments and are not always able to fill orders immediately. Not all materials sent abroad by the Soviets are of high caliber, so care should be taken to check publication date and, if possible, read an abstract of the book or article before ordering. Prices, which reflect Soviet subsidies, are apparently no guide to quality. Since the supply varies, the reader should contact one of these sources and ask to be put on the mailing list.

Some of the better dictionaries, if not out of print, are at least difficult to obtain. The Library of Congress lists some 12 geologic dictionaries and glossaries in Russian alone. Those who cannot visit the library themselves may obtain some of the materials through the Lending Libraries Union, which services professional societies and some local libraries. The Library of Congress publishes a brochure on how this service works, if your local library does not know. The dictionaries listed below may possibly be secured through used-book trade channels, so both Library of Congress call number and bibliographic data are given where known.

Outstanding for precision is Alejandro Novitsky's Diccionario minero, metalurgico, geologico, mineralogico, petrografico y des petroles (Buenos Aires, Argentina, 1951). This two-volume polyglot dictionary lists 18,000 terms in English, French, Spanish and German. Call number is QE 5.A5. Translator Alexandrov praises the accuracy of the Novitsky with the qualification that it contains only 69 percent of the words found in a Russian text of general geology, 81 percent of petrography and lower scores for petroleum and mineralogy.

Others are:

QE5.L46: Krishtofovich, A. N. (ed. T. N. Spizharsky), Geologicheskyy Slovar: Gosud. nauchno-tech. iz-vo lit-ry po geologii i okhrane nedr, Moscow, 1955. This two-volume, all-Russian geologic dictionary contains an estimated 1,500 terms and a geologic time chart.

QE5.G58: Glossary of Strata Control Terms

in English, French and German, jointly prepared by the Institut national de l'industrie charbonniere (France), Steinkohlenbergbauverein (Germany) and the National Coal Board (England): N. C. B., London, 1958.

QE5.H85: Huebner, Walther, Geology and Allied Sciences, Thesaurus and a Coordination of English and German Allied Terms, Veritas Press, New York, 1939.

QE5.L4: Leningrad Tsentralniye nauchno-issledovatel'skiy geologorazvedochnyy institut, Slovar po Geologiya-Razvedochnomy Delu, edited by A. K. Meyster: Leningrad.

QE5.A5: T. A. Sofiyano, Anglo-Russian Geologicheskyy Slovar (edited by D. C. Korzhinsky): Izd-vo tekhniko-teoret. lit-ry, Moscow, 1957. This 521-page dictionary has no reversed index; definitions favor transliteration but more than one Russian term is frequently given for the English.

QE5.L42: Leningrad tsentralniye nauchno-issledovatel'skiy geologorazvedochnyy institut, Stratigraficheskyy Slovar (edited by A. A. Borisyak): Lenin. gos. nauch. tekhn. gorno-geol. -neftyanoe izd-vo, 1933.

Since geologists are rarely concentrated in the metropolitan areas with the best libraries, they should check their own areas for the best university or mining-college collection and perhaps join forces with nearby colleagues who are also interested in original Russian material.

For reasons of satisfaction or remuneration, the geologist who reads Russian well enough to translate may find himself preparing manuscripts for publication (for International Geology Review, we hope). Whether for a commercial house or a professional journal, the manuscript must follow - in addition to the usual rules on readability, grammar, references and footnotes - some fine points without which some of the translation's value is lost.

A general reference on manuscript preparation is Suggestions to Authors of the Reports of the United States Geological Survey, 5th edition, sold through the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. (\$1.75). Bearing directly on the field of geology, it contains a table for proper capitalization of geologic periods (Upper Cretaceous but upper Oligocene), detailed directions on tables, footnotes and references and a readable guide to refreshing some forgotten points of grammar expressed, appropriately, in such examples as "The rocks are mostly gray slate with [but include] some graywacke."

The mention of "references" brings up one of the duties of the translator: transliteration.



## REFERENCE SECTION

This paper is not complete until all Cyrillic titles in the list of references are transliterated according to the system preferred by his customer and translated (publishing sources are left merely transliterated). They must also be arranged in order. The sequence may be either by numerical order of appearance in the text or alphabetical order of authors' names. In the latter case, the authors' last name and the date of the reference are listed in parentheses in the body of the text. It must be noted that the Cyrillic alphabet, when transliterated, does not follow English alphabetical order. Soviet writers also list all Russian sources first, then foreign sources. For an American journal, these two lists must be combined into one.

The same transliteration system must be used throughout the manuscript. This is especially important when no definition of a word can be found. Any translator's note, such as suggested alternate meaning or comment on the text, is enclosed in brackets — not parentheses. This is necessary to distinguish a (?) inserted by the original author from a [?] indicating the translator is not sure of the translation.

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### NEW PUBLICATIONS OF THE OFFICE OF TECHNICAL SERVICES OF INTEREST TO GEOLOGISTS

The Office of Technical Services, U. S. Department of Commerce has recently announced additional services and publications to improve foreign-literature reporting to American scientists. A number of these show promise of being useful to researchers in geology.

1. A weekly publication Current Review of the Soviet Technical Press contains abstracts or brief reviews of articles from recent Soviet books and journals. An analysis of three issues of this publication shows that of the approximately 170 papers reviewed, 5 are of primary geologic interest: Earth Current Recordings, Electrical Prospecting Equipment, "Marsquakes," New Polar Geophysical Institute, and Destruction of Rocks by High Energy Impact.

2. A monthly publication English Abstracts of Selected Articles from Soviet Bloc and Mainland China Technical Journals in six series, of which two include subjects of primary interest to geologists. Series I covers physics, geophysics, astrophysics, astronomy, astronautics, and applied mathematics. Series VI covers general science and miscellaneous, including meteorology, oceanography, biology, astrobiology, botany, zoology, medical science, aeromedicine, education, fuels, fuel products, and power. Each of these series will include about 225 abstracts per month and cost \$9 for six issues.

3. Publication SB - 442, Chinese Mainland Science and Technology is a selective bibliography of more than 300 reports announced on the subject in OTS' monthly abstracts journals: U. S. Government Research Reports and Technical Translations. A total of 81 reports in the earth sciences are cited. Cost of the bibliography is 10 cents.

4. To meet special needs which are not covered by a currently available OTS Selective Bibliography, the Office of Technical Services, in association with the Science and Technology Division of the Library of Congress, offers a service through which special literature searches will be performed for payment of a fee based on the time required to prepare a bibliography.

In this service the Office of Technical Services will compile lists of relevant publications in the OTS holdings of Government research reports, unclassified and declassified Atomic Energy Commission reports, technical translations, and OTS files of Government-owned patents. Similarly, the Science and Technology Division of the Library of Congress will cite pertinent references from examination of the general collections of the Library and of appropriate index and abstract publications. For additional information write to:

Technical Information Division  
Office of Technical Services  
Washington 25, D. C.

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### LIST OF FRENCH GEOLOGIC WORKS AVAILABLE

Readers interested in French-language documents on geology, mineralogy and mining can get a complete list of periodicals covering this field from the Bureau de Recherches Géologiques et Minières, 74, Rue de la Fédération, Paris, XV. The Bureau, interested in taking a census of researchers who read French scientific literature and in learning about any difficulties they may have in procuring it, will enclose a return-postcard questionnaire and a plan (in six languages, including English) for codification of earth and mining sciences. Sample copies of periodicals will be sent upon request. -- France Actuelle.

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### MAP OF THE INDIAN OCEAN

The Institut Geographique National has announced publication of a map of the Indian Ocean, on the occasion of the International Indian Ocean Expedition.

The map has been prepared using the Mercator projection, with a scale of 1:10,000,000 at the Equator.



## INTERNATIONAL GEOLOGY REVIEW

Size is 40 x 50 inches and completely covers the region between meridians 18°E. and 128°E. and parallels 31°N. and 46°40'S. Land relief is shown in hypsometric tints, and ocean bottom relief by bathymetric contours. It is printed in 8 colors. Price: 10 NF or \$2 (or 15 shillings) per copy, including postage. Discounts for

larger orders are allowed.

Orders should be addressed to:

Institut Géographique National,  
136 bis rue de Grenelle,  
Paris 7<sup>e</sup>.















